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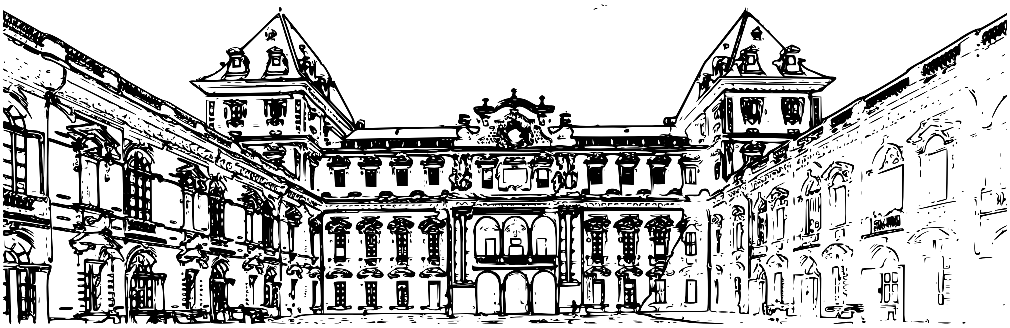

17-20 June 2018 - Turin - ITALY

# ICMAMS

## First International Conference on Mechanics of Advanced Materials and Structures

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# Proceedings of the First International Conference on Mechanics of Advanced Materials and Structures - ICMAMS 2018

Castello del Valentino, Torino, Italy

17-20 June 2018

Chairmen
J.N. Reddy and Erasmo Carrera

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Matteo Filippi
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Marco Petrolo
Enrico Zappino

ISBN: 9791220033114

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## Monday Morning / 18 June / Aula 1V

**0900 - 1030** **Plenary Talks**

Chaired by Antonio Ferreira, Universidade do Porto

**0900 - 0945**

J.N. Reddy

Texas A&M University

*A journey through composite materials and structures: a personal retrospective*

**0945 - 1030**

Adhikari Sondipon

Swansea University

*Dynamic homogenisation of randomly irregular metamaterials*

## Monday Morning / 18 June / Salone d'Onore

**Session 4** **Biomechanics**

Chaired by Ugo Galvanetto (U Padova), Antonio Gloria (CNR-IPCB)

| 1100 | 1125 | 1150 | 1215 |
|---|---|---|---|
| Numerical simulation of penetrating impact in a biological tissue simulant using meshless method | Microgravity-induced structural changes in ISS-mice reduce femoral stiffness by one third: results from a micro-CT-image-based Bernoulli-Sapountzakis beam theory, validated by 3D FEM | Advanced models for the nonlinear static response of biological structures | Metal posts and effect of material-shape combination on the mechanical behaviour of endodontically treated anterior teeth |
| H. Frissane, L. Taddei, N. Labaal, S. Roth | A. Kurfürst, S. Tavella, A. Giuliani, F. Rustichelli, R. Cancedda, C. Hellmich | D. Guarnera, E. Carrera, I. Kaleel, A. Pagani, M. Petrolo | S. Maietta, M. Martorelli, P. Ausiello, M. Richetta, R. Montanari, A. Lanzotti, A. Gloria |

## Monday Morning / 18 June / Sala Zodiaco

**Session 5** **Design for additive layer manufacturing**

Chaired by Massimo Martorelli (U Napoli), Marco Montemurro (ENSAM Bordeaux)

| 1100 | 1125 | 1150 | 1215 | 1240 |
|---|---|---|---|---|
| Dynamic response evolution of damaged SLM lattice structures | Conceptual design and analysis of a multi-component interbody fusion device | Multi-scale optimization of lattice structures for biomechanical components | Numerical simulation of the multiaxial fatigue behavior of titanium lattice structures | A geometry-based method for 3D topology optimization |
| G. De Pasquale, A. Mura | S. Maietta, M. Martorelli, O. de Diviitis, M. Richetta, R. Montanari, A. Lanzotti, A. Gloria | M. Montemurro, G. De Pasquale, G. Bertolino | K. Refai, C. Brugger, M. Montemurro, N. Saintier | G. Costa, M. Montemurro, J. Pailhès |

## Monday Morning / 18 June / Sala Caccia

**Session 3** **Nonlocal modelling of nano-structures and composites-I**

Chaired by Raimondo Luciano (U Cassino), Olivier Polit (U Parix Nanterre)

| 1100 | 1125 | 1150 | 1215 | 1240 |
|---|---|---|---|---|
| Geometrical reconstruction of concrete materials through the aid of advanced measurement techniques and studies of their mechanical behavior | A nonlocal higher-order curved beam model for bending, stability, free and force vibrations | Nonlocal modeling of elastic nano-structures | Prediction of debonding onset in fiber-reinforced polymer composites via a global-local approach | Unified theory of structures based on micropolar elasticity |
| G. Mazzucco, G. Xotta, B. Pomaro, V.A. Salomoni, C.E. Majorana | O. Polit, M. Ganapathi, T. Merzouki | R. Barretta, R. Luciano | F. Greco, L. Leonetti, P. Lonetti, R. Luciano, A. Pranno | R. Augello, E. Carrera, A. Pagani |

## Monday Morning / 18 June / Sala Gigli

**Session 11** **Advances in modeling and design of smart structures-I**

Chaired by Aurelio Araujo (U Lisboa), Michael Krommer (TU Wien), Filipa Moleiro (U Lisboa), Enrico Zappino (Polito)

| 1100 | 1125 | 1150 | 1215 | 1240 |
|---|---|---|---|---|
| Buckling of and wave propagation in functionally graded dielectric elastomeric hollow cylinders | Industrialization of a kinematic vibration energy harvester for smart bearing with piezoelectric/magnetic coupling | Actuator placement in adaptive structures - Redundancy distribution vs. disturbance compensability | Bending of piezo-electric functionally graded plates | Non-linear modeling of piezoelectric materials: a phenomenological approach to large deformation and hysteresis |
| B. Wu, W.Q. Chen | E. Brusa | M. von Scheven, F. Geiger, J. Gade, J. Wagner, O. Sawodny, M. Bischoff | V. Sladek, L. Sator, M. Repka, J. Sladek | A. Humer, A.S. Pechstein, M. Krommer |

## Monday Afternoon / 18 June / Salone d'Onore

**Session 6** **Nanotechnology-I**

Chaired by Antonio Gloria (CNR-IPCB), Samit Roy (U Alabama)

| 1400 | 1425 | 1450 | 1515 |
|---|---|---|---|
| Indentation tests of two-dimensional materials with substrates | Vibrations of functionally graded graphene reinforced porous nanocomposite cylindrical shells | Graphene coating to enhance tribological performance of steels | Anomalous fracture behavior of graphene due to nano-scale size effect |
| G. Cao | Y.H. Dong, Y.H. Li, J.Yang | A. Mura, J. Kong, H. Wang, F. Adamo | S. Roy |

## Monday Afternoon / 18 June / Sala Zodiaco

**Session 2** **CASTLE project and metamaterials-I**

Chaired by Maria Cinefra (Polito), Sergio De Rosa (U Napoli)

| 1400 | 1425 | 1450 | 1515 |
|---|---|---|---|
| Overview on metamaterials for acoustic applications | Investigation of mechanical properties on 3D-printed structured beams to increase vibration absorption | Three-dimensional Floquet waves in periodically multilayered anisotropic elastic media | Thermo-mechanical buckling of sandwich structures with FRP faces and FGM core |
| G. Bellezza, G. D'Amico, M. Cinefra, G. Petrone, S. De Rosa | G. Robin, E.M. Daya | Q.Q. Li, Y.Q. Guo | A. Muc, M. Chwal |

## Monday Afternoon / 18 June / Sala Caccia

**Session 3** **Nonlocal modelling of nano-structures and composites-II**

Chaired by Raimondo Luciano (U Cassino), Olivier Polit (U Paris Nanterre)

| | 1425 | 1450 | 1515 |
|---|---|---|---|
| | Comparison between Eringen's differential nonlocal model and Laplace's fractional operator approach | Peridynamic modelling of reinforced concrete beams | Size dependent bending, buckling and free vibration of two directional functionally graded microbeams based on the modified coupled stress theory and a unified formulation |
| | G. Autuori, F. Cluni, V. Gusella, P. Pucci | N. Sau, J. Medina, A. Borbon | J.L. Mantari, J. Yarasca |

## Monday Afternoon / 18 June / Sala Gigli

**Session 11** **Advances in modeling and design of smart structures-II**

Chaired by Aurelio Araujo (U Lisboa), Michael Krommer (TU Wien), Filipa Moleiro (U Lisboa), Enrico Zappino (Polito)

| 1400 | 1425 | 1450 | 1515 |
|---|---|---|---|
| Layerwise mixed model for analysis of multilayered plates with embedded functionally graded material layers | Three-dimensional elastic waves in multilayered piezoelectric-elastic composites with negative permittivities | Transient response of an interface crack between piezoelectric-piezomagnetic layered structures under magnetoelectromechanical impact loadings | Large amplitude vibrations of pre-stressed piezo-actuated circular plates |
| F. Moleiro, V.M. Franco Correia, A.L. Araújo, C.M. Mota Soares, J.N. Reddy | Y.Q. Guo, L.T. Guo, W. Wang | Z. Yan, W.J. Feng | F. Toth, M. Krommer, M. Kaltenbacher |

## Monday Afternoon / 18 June / Salone d'Onore

**Session 6** **Nanotechnology-II**

Chaired by Antonio Gloria (CNR-IPCB), Samit Roy (U Alabama)

| 1600 | 1625 | | 1715 |
|---|---|---|---|
| Evaluation of thermo-mechanical properties for CNT/epoxy nano-composites | The use of peridynamics in the study of crack propagation in solid materials | | Characterization of the effect of adding titanium dioxide on the hydroxyapatite deposited on the 316L substrate for biomedical application |
| M. Chwal, A. Muc | U. Galvanetto, S. Bazazzadeh, T. Ni, A. Shojaei, M. Zaccariotto | | D.J. Sidane, H. Khireddine, S. Yala |

## Monday Afternoon / 18 June / Sala Zodiaco

**Session 2** **CASTLE project and metamaterials-II**

Chaired by Maria Cinefra (Polito), Sergio De Rosa (U Napoli)

| 1600 | 1625 | 1650 | 1715 |
|---|---|---|---|
| Electrospun materials for soundproofing | Aircraft interior noise prediction through statistical energy analysis method | Concept of a human response model for aircraft cabin interiors design in virtual environments | Hierarchical Legendre expansion for the dynamic response and wave propagation of metallic and composite beams |
| F. Branda, F. Marulo, A. Bifulco, J. Passaro, G. Petrone, M. Guida | G. Petrone, S. De Rosa | F. De Crescenzio, F. Lucchi, S. Bagassi | A.G. de Miguel, Y. Yan, A. Pagani, E. Carrera |

## Monday Afternoon / 18 June / Sala Caccia

**Session 10** **Classical and non-classical continuum theories and constitutive theories for solid continua-I**

Chaired by J.N. Reddy (Texas A&M), Karan S. Surana (U Kansas)

| 1600 | 1625 | 1650 | 1715 |
|---|---|---|---|
| Thermodynamically consistent beam theories in context of classical and non-classical continuum mechanics | Consistent thermoviscoelastic beam theories without memory in context of classical and non-classical continuum mechanics approach | Thermoviscoelastic beam theories with memory in context of classical and non-classical continuum mechanics | Study on the subsequent yielding surface and constitutive equation of metallic foam under multi-axial loading |
| K.S. Surana, R. Anusuri, D. Mysore, J. N. Reddy | K.S. Surana, D. Mysore, J. N. Reddy | K.S. Surana, D. Mysore, J. N. Reddy | D. Qiao, L. Tang, Y. Wu, Z. Liu, L. Zhou |

## Monday Afternoon / 18 June / Sala Gigli

**Session 11** **Advances in modeling and design of smart structures-III**

Chaired by Aurelio Araujo (U Lisboa), Michael Krommer (TU Wien), Filipa Moleiro (U Lisboa), Enrico Zappino (Polito)

| 1600 | 1625 | 1650 | 1715 |
|---|---|---|---|
| Stick and slip piezo motors modelling | Analysis of FSI-driven energy harvesting devices using parameterised reduced-order models | Nonlinear modeling of dielectric elastomer actuators accounting for electrostriction and polarisation saturation | Vibration of a honeycomb sandwich structure with an on face bonded macro fiber composite |
| A. Pagès, F. Battistello, A. Guignabert, O. Freychet, C. Belly, F. Barillot | A. Zilian, D. Baroli | E. Staudigl, M. Krommer | A. Benjeddou |

## Monday Afternoon / 18 June / Aula 1V

**1740 - 1910** **Plenary Talks**

Chaired by Weiqiu Chen, Zhejiang University

**1740 - 1825**

Erdogan Madenci

The University of Arizona

*Peridynamics for paradigm shift in computational methods*

**1825 - 1910**

Maenghyo Cho

Seoul National University

*Multiscale analysis of photo-responsive nanocomposites and realization*

## Tuesday Morning / 19 June / Aula 1V

**0830 - 1000** **Plenary Talks**

Chaired by Bruno Castanié, Université de Toulouse

**0830 - 0915**
Ferdinando Auricchio
Università di Pavia
*Additive manufacturing: materials and computational mechanics*

**0915 - 1000**
Evan Pineda
NASA Glenn
*Multiscale modeling of fiber reinforced composites considering nonlinear effects*

## Tuesday Morning / 19 June / Aula 1V

**Session 7** **Integrated Computational Materials Engineering (ICME) for advanced structures-I**

Chaired by Marianna Maiarù (U Mass Lowell), Evan J. Pineda (NASA)

| 1030 | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| Numerical model of DCB test of fiber metal laminate | Computational homogenisation for thermo-mechanical properties of cork-based composites | Flexural failure analysis of composite structural insulated panels with MGO board facings | Stochastic time domain spectral element formulation of sandwich beams | Artificial microstructure generation for representative volume elements of fiber reinforced composites | Relative study on sandwich structures reinforced in thickness: numerical approach |
| M. Kamocka, R.J. Mania | M. Delucia, A. Catapano, M. Montemurro, J. Pailhès | L. Smakosz, I. Kreja | S. Mukherjee, S. Gopalakrishnan, R. Ganguli | S.E. Stapleton, H. Krieger, G. Barlow, E.G. Zhou, D.H. Mollenhauer | M. El Moussaid, P. Sansen, C. Lainé, S. Panier |

## Tuesday Morning / 19 June / Sala Zodiaco

**Session 12** **Beam, plate and shell structures-I**

Chaired by Gennady Kulikov (U Tambov), Arcangelo Messina (U Salento)

| 1030 | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| Advanced design rules for ring-stiffened shells subject to axial compression | Homogenization of nonlinear highly heterogeneous shell | Finite rotation exact geometry shell element for 3D stress analysis of composite structures | Enhanced beam-theory derived shear stress distributions in tramway rails | Testing the frequency range of Timoshenko beam theory | Sublaminate variable-kinematic models for vibroacoustic analysis of composite trim panels |
| A. Jäger-Cañás, H. Pasternak | E. Pruchnicki | G.M. Kulikov, S.V. Plotnikova | P. Hasslinger, A. Kurfürst, T. Hammer, E. Fischmeister, C. Hellmich, S. Scheiner | A. Messina, G. Reina | L. Dozio, R. Vescovini, M. D'Ottavio |

## Tuesday Morning / 19 June / Sala Caccia

**Session 14** **Multiphysics-I**

Chaired by Ferdinando Auricchio (U Pavia), Fiorenzo Fazzolari (U Liverpool)

| 1030 | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| Band-gap properties of phononic crystal beams with fluid-solid coupling | Finite element analysis for three-dimensional flows of generalized Newtonian fluids | Electro-chemo-mechanical model for polymer electrolyte membranes | A viscoplasticity model for metals with two-temperature thermodynamics | Resolution of unsteady heat conduction problem with arbitrary heat source location | A thermomechanical theory for hyperelastic semi-linear material |
| K.C. Chuang, X. Fang, Z.W. Yuan | N. Kim, J.N. Reddy | M. Rossi, T. Wallmersperger, P. Nardinocchi, E. Puntel | G. Kar, D. Roy | L. Aboudou, P. Vidal, I. Ranc, L. Gallimard | O.O. Fadodun, A.S. Borokinni, O.P. Layeni, A.P. Akinola |

## Tuesday Morning / 19 June / Sala Gigli

**Session 11** **Advances in modeling and design of smart structures-IV**

Chaired by Aurelio Araujo (U Lisboa), Michael Krommer (TU Wien), Filipa Moleiro (U Lisboa), Enrico Zappino (Polito)

| | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| | A novel triangular shell element for piezoelectric smart structures | Optimal location of piezoelectric patches for noise reduction in sandwich panels | Vibration control of a footbridge using a vibration absorber integrating a magnetorheological brake | Node-dependent kinematic elements for the analysis of energy harvester | Experimental and numerical investigation of Free vibration analysis and control of composite plates with and without delamination |
| | D. Marinkovic, G. Rama, M. Zehn | A.L. Araujo, J.F.A. Madeira, F. Moleiro | C. Moutinho, F. Magalhaes, E. Caetano, A. Cunha | E. Zappino, E. Carrera | P.K. Mahato, J.P. Varun, G. Shankar, S. Kumar, C.S.Verma |

## Tuesday Afternoon / 19 June / Aula 1V

**Session 7** — **Integrated Computational Materials Engineering (ICME) for advanced structures-II**

Chaired by Marianna Maiarù (U Mass Lowell), Evan J. Pineda (NASA)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| Variability of mechanical properties of viscoelastic sandwich structures determined by an inverse identification method | An approach for modelling the damping of flax-epoxy laminated composite | A component-wise formulation for virtual testing of composites | Material charcterization and modeling of graphene nanoplatelets reinforced composited for ICME studies | Modeling-Driven Design of Spacecraft Hardware with Improved Shear Toughening Using Graphene Nanoplatelet/Carbon Fiber/Epoxy Hybrid Composites |
| K.S. Ledi, M. Hamdaoui, G. Robin, E.M. Daya | L. Duigou, S. Mahmoudi, J.M. Cadou, E.M. Daya, G. Robin | I. Kaleel, A.G. de Miguel, M.H. Nagaraj, A. Pagani, M. Petrolo, E. Carrera | M. Maiarù, M. Salviato, Y. Qiao, S. Shah | J. Tomasi, W. Pisani, S. Chinkanjanarot, A.S. Krieg, E. Pineda, B. Bednarcyk, S. Miller, J. King, I. Miskioglu, G. Odegard |

## Tuesday Afternoon / 19 June / Sala Zodiaco

**Session 13** — **Damage and failure**

Chaired by Bruno Castanié (U Toulouse), Alberto Milazzo (U Palermo)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| Continuum damage modeling of shear postbuckling in honeycomb core | Computational homogenisation and microcracking analysis of piezoelectric ceramics | A reduced model for handling the instabilities of long fiber reinforced composite with multilevel finite element method | Multiple cracks localization for thin coating film layers in pure bending | A study of interfacial property of composite based on energy-based debonding criterion |
| J. De Dios Rodriguez, B. Castanie, C. Bouvet | I. Benedetti, V. Gulizzi, A. Milazzo | R. Xu, Y. Hui, Q. Huang, H. Hu, H. Zahrouni, T. Ben Zineb, S. Zhu | G. Borino, F. Parrinello | P.Y. Pei, Y. Shi, H. Qing, C.F. Gao |

## Tuesday Afternoon / 19 June / Sala Caccia

**Session 10** — **Classical and non-classical continuum theories and constitutive theories for solid continua-II**

Chaired by J.N. Reddy (Texas A&M), Karan S. Surana (U Kansas)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| Strain-rate modelling of composite materials by a fractional derivative approach | Finite element model updating for identification of constitutive parameters in strain gradient theory | A variational approach to brittle fracture and interface decohesion in composites: theory and applications | Internal resonances in dynamics of nonlinear plates | The rigid-body plastic analysis of free-end torsion problem using a newly developed constitutive equation based on the plastic spin concept |
| A. Krasnobrizha, O. Polit, E. Valot | I. Jeong, E. Kim, M. Cho | M. Paggi, J. Reinoso, V. Carollo | M.V. Shitikova, E.I. Osipova | H. Mehdipour, G. Belingardi |

| Tuesday Afternoon / 19 June / Sala Gigli | | | | |
|---|---|---|---|---|
| **Session 9** **Analysis and design of variable angle tow laminates**<br>Chaired by Anita Catapano (U Bordeaux), Marco Montemurro (ENSAM Bordeaux) | | | | |
| 1400 | 1425 | 1450 | 1515 | 1540 |
| An experimental validation of the effectiveness of quasi-trivial solutions for composite laminates | Strength optimisation of variable angle tow laminates | Non uniform rational b-splines (NURBS) hypersurfaces for metamodeling: application to a composite stiffened panel | Implicit mesh discontinuous Galerkin for variable angle tow multilayered plates | Analyses of VAT composite structures using a layer-wise 1-D model |
| M. Montemurro, M.I. Izzi, J. El-Yagoubi, D. Fanteria | A. Catapano, M. Montemurro, F. Chinesta | Y. Audoux, M. Montemurro, J. Pailhes | V. Gulizzi, I. Benedetti, A. Milazzo | A. Viglietti, E. Zappino, E. Carrera |

| Tuesday Afternoon / 19 June / Aula 1V | |
|---|---|
| **1630 - 1800** | **Plenary Talks**<br>Chaired by Aurelio Araujo, University of Lisbon |
| **1630 - 1715** | Cun-Fa Gao<br>Nanjing University of Aeronautics and Astronautics<br>*Dielectric breakdown modelling in a cracked piezoelectric solid* |
| **1715 - 1800** | C.W. Lim<br>City University of Hong Kong<br>*Thermo-acoustic radiation of free-standing nano-thin film in viscous fluid* |

## Wednesday Morning / 20 June / Aula 1V

**0915 - 1000** **Plenary Talk**

Chaired by Olivier Polit, Université Paris Nanterre

Erasmo Carrera

Politecnico di Torino

*Recent developments on the Carrera Unified Formulation*

## Wednesday Morning / 20 June / Salone d'Onore

**Session 8** **COMPOSELECTOR project**

Chaired by Salim Belouettar, Gaetano Giunta (LIST)

| 1030 | 1055 | 1120 | 1145 | 1210 |
|---|---|---|---|---|
| Multiscale molecular simulations for nanocomposite materials | Integrating atomistic and mesoscopic molecular simulations and industrial business decisions for nanocomposite materials. The COMPOSELECTOR experience | MuPIF - A platform for integrating material and process models into a workflow | Micromechanics-based multiscale modeling for nonlinear analysis of fiber-reinforced composites using DIGIMAT | Global-local techniques for macroscale analysis and key performance indicator evaluation of composite structures |
| D. Marson, E. Laurini, M. Fermeglia, S. Pricl | E. Laurini, D. Marson, M. Fermeglia, S. Pricl | M. Horák, B. Patzák, V. Smilauer, S. Sulc | I. Kaleel, M. Petrolo, E. Carrera, M. Giugno, M. Linari | M.H. Nagaraj, I. Kaleel, M. Petrolo, E. Carrera |

## Wednesday Morning / 20 June / Sala Zodiaco

**Session 12** **Beam, plate and shell structures-II**

Chaired by Christian Hellmich (TU Wien), Olivier Polit (U Nanterre)

| 1030 | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| Rigorous amendment of Vlasov's theory for thin elastic plates on elastic Winkler foundations | Snap-back mechanisms of rods subject to kinematic boundary conditions | Robust CUF-based mixed and hybrid plate elements | Asymptotic analysis of ring-stiffened cylindrical shells buckling | On the unsymmetrical buckling of the nonuniform shallow spherical shells under internal pressure | Modal analysis of rotating viscoelastic asymmetric sandwich beams |
| R. Hoeller, M. Aminbaghai, L. Eberhardsteiner, J. Eberhardsteiner, R. Blab, B. Pichler, C. Hellmich | A. Cazzolli, F. Dal Corso, D. Bigoni | T.H.C. Le, M. D'Ottavio, P. Vidal, O. Polit | S.B. Filippov | S. Bauer, E. Voronkova, K. Minina | F. Boumediene, F. Bekhoucha, E.M. Daya |

## Wednesday Morning / 20 June / Sala Caccia

### Session 14 Multiphysics-II

Chaired by Fiorenzo Fazzolari (U Liverpool), Marco Paggi (IMT Lucca)

| 1030 | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| Structural (multielement) model with the thermomechanical exposure memory | Effects of temperature-dependent material properties on thermo-mechanical analysis of in-plane two-dimensional functionally graded circular plates | Control of thermomechanical anisotropy of high speed rotor with permanent magnets in micro energy harvesters | Study on thermal properties of thermoelectric CoSb3 and Mg2Si using molecular dynamics method | Effect of temperature gradient upon load induced thermal strain of heated, stressed concrete in transient state test | Study of vibration analysis of microstretch thermoelastic rectangular plate |
| V. Astashkin, M. Mishnev | M. Didem Demirbas, M. Kemal Apalak | E. Brusa, E. Ossola | Y. Cao, Y. Zhang, Y.C. Chu | K. Fan, L.Y. Li, D. Li | N. Chugh |

## Wednesday Morning / 20 June / Sala Gigli

### Session 1 FULLCOMP project and composites-I

Chaired by Erasmo Carrera, Marco Petrolo (Polito)

| 1030 | 1055 | 1120 | 1145 | 1210 | 1235 |
|---|---|---|---|---|---|
| Global hybrid strategy for multi-scale characterization of composite material properties with non-destructive tests | PDSO application for FE based design of a damping system for smart composite structure | Stochastic strength prediction of braided composites: multiscale damage modeling and uncertainty quantification | Effect of random spatial stiffness variations on the postbuckling behavior of layered structures | A non-iterative method for designing topologically efficient buckling-resistant structures | High speed impact damage prediction using the smart materials |
| L. Cappelli, M. Montemurro, F. Dau, L. Guillaumat | A. Alaimo, A. Esposito, C. Orlando | G. Balokas, S. Czichon, B. Kriegesmann, R. Rolfes | S. van den Broek, E. Jansen, R. Rolfes | S. Minera, M. Patni, P.M. Weaver, A. Pirrera | R. Basavanna, S. Raja, Karisiddappa |

## Wednesday Afternoon / 20 June / Salone d'Onore

### Session 15 Characterization, processing, manufacturing, testing-I

Chaired by Michele D'Ottavio (U Nanterre), Liqun Tang (U Guangzhou)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| Study of the influence of coupling agents over the adhesion force of dissimilar overmolding polymers: a digital image correlation analysis<br><br>L. Pisanu, J.D.V Barbosa, P.A.M.G.P. Bamberg, B. Marx, A. Schiebahn, R.J. Alves de Sousa, M.L.F. Nascimento | Characterization of the adhesive bonding between hyperelastic material and surface treated fibers<br><br>J. Beter, B. Schrittesser, P. Fuchs | Deep cryogenic treatment effects on wear properties of AA6061 metal matrix composites<br><br>P. Baldissera, C. Delprete | Buckling induced three-dimensional origami structures and their applications<br><br>Y. Shi, Y. Zhang, C. Gao | An invariant-based design of CFRP laminates<br><br>J.D.D. Melo, S.W. Tsai |

## Wednesday Afternoon / 20 June / Sala Zodiaco

### Session 12 Beam, plate and shell structures-III

Chaired by Ranjan Banerjee (C U London), Volodymyr Zozulya (CICY Yucatan)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| An exact dynamic stiffness method incorporating Rayleigh-Love bar and Timoshenko beam theories for free vibration analysis of plane frames<br><br>J.R. Banerjee, A. Ananthapuvirajah | Vibrational spectra of thin elliptic plates<br><br>A.L. Smirnov, E.A. Dolgova | Multi objective optimization of lattice structure using 3D beam and shell FE analysis<br><br>N. Labaal, S. Gomes | Surrogate modelling of aerospace structures for damage detection and classification<br><br>E. Carrera, A. Pagani | Nonlocal theory of plates, shells and beams. Higher order, Timoshenko's and Euler-Bernoulli models<br><br>A. Czekanski, V.V. Zozulya |

## Wednesday Afternoon / 20 June / Sala Caccia

### Session 14 Multiphysics-III

Chaired by Fiorenzo Fazzolari (U Liverpool), Marco Paggi (IMT Lucca)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| Thermoelasticity with second sound in variable thickness disks via Carrera Unified Formulation<br><br>A. Entezari, E. Carrera, M. Filippi | Crack analysis in magneto-electro-elastic solids by gradient theory<br><br>J. Sladek, V. Sladek, M. Wünsche | Challenges of hp-adaptive FEM for coupled problems of piezoelectricity<br><br>G. Zboinski | Modal analysis of temperature-dependent FG carbon nanotube-reinforced composite plates in thermal environment<br><br>F.A. Fazzolari | Thermal post-buckling of laminated composite structures with temperature dependent properties<br><br>F. Abdoun, L. Azrar, E.M. Daya |

## Wednesday Afternoon / 20 June / Sala Gigli

**Session 1** **FULLCOMP project and composites-II**

Chaired by Erasmo Carrera, Marco Petrolo (Polito)

| 1400 | 1425 | 1450 | 1515 | 1540 |
|---|---|---|---|---|
| Hierarchical beam finite elements for multi-scale geometrically nonlinear analysis of beam structures via multi-scale asymptotic numerical method | Two-way global-local approach for progressive failure analysis applied to a large stiffened composite panel with intralaminar damage and skin-stringer debonding | Newton's series expansion based theories in the framework of Carrera's Unified Formulation for the analysis of plates | Three-dimensional stress distribution in tow-steered composite structures | Advanced models for the accurate evaluation of interlaminar stresses in composites with applications to free-edge effects and delamination |
| Y. Hui,<br>G. Giunta,<br>G. De Pietro,<br>S. Belouettar,<br>H. Hu,<br>E. Carrera | M. Akterskaia,<br>E. Jansen,<br>R. Rolfes | G. Giunta,<br>G. De Pietro,<br>Y. Hui,<br>S. Belouettar | M. Patni,<br>S. Minera,<br>P.M. Weaver,<br>A. Pirrera | A.G. de Miguel,<br>E. Carrera,<br>A. Pagani,<br>E. Zappino |

## Wednesday Afternoon / 20 June / Salone d'Onore

**Session 15** **Characterization, processing, manufacturing, testing-II**
Chaired by Michele D'Ottavio (U Nanterre), Liqun Tang (U Guangzhou)

| 1630 | 1655 | 1720 | 1745 |
|---|---|---|---|
| SLM-EBM processes optimizaton for metal lattice structures fabrication | Influence of friction reduction pad on the mechanical behavior of concrete subjected to 3-D passive confinement | Accurate stress analysis of bonded joints via higher-order models | Characterization of mechanical components manufactured via additive and subtractive process: a comparison of the behavior under low-velocity impacts |
| G. De Pasquale,<br>F. Luceri,<br>M. Romeo | I.A. Tijani,<br>C.W. Lim | A.G. de Miguel,<br>L. Rizzo,<br>A. Catapano,<br>E. Carrera,<br>A. Pagani,<br>E. Panettieri | P. Lesage,<br>L. Dembinski,<br>S. Gomes,<br>S. Roth |

## Wednesday Afternoon / 20 June / Sala Caccia

**Session 14** **Multiphysics-IV**
Chaired by Fiorenzo Fazzolari (U Liverpool), Marina Shitikova (U Voronezh)

| 1630 | 1655 | 1720 | |
|---|---|---|---|
| Component-wise models for the analysis of composite structures exposed to aging phenomena | Mode shape variations of thickness-shear vibrations of quartz crystal plates in a thermal field | Time fractional vibration of magnetohyperelastic thin disc | |
| E. Zappino,<br>E. Carrera | Q. Huang,<br>R. Wu,<br>L. Xie,<br>J. Du,<br>J. Wang | A. P. Akinola,<br>O.O. Fadodun,<br>A.S. Borokinni,<br>O.P. Layeni | |

## Wednesday Afternoon / 20 June / Sala Gigli

**Session 1** **FULLCOMP project and composites-III**
Chaired by Erasmo Carrera, Marco Petrolo (Polito)

| 1630 | 1655 | 1720 | 1745 |
|---|---|---|---|
| Geometrically non-linear hierarchical finite elements for the analysis of bi-stable beam structures | Multi-scale modeling of heterogeneous elastic solids based on control of modeling errors in local quantities of interest | Contact modeling within displacement-based refined one dimensional beam models | Modeling of composite structures with piezoelectric components by refined finite elements |
| G. De Pietro,<br>G. Giunta,<br>Y. Hui,<br>S. Belouettar,<br>H. Hu,<br>E. Carrera | A. Romkes,<br>J.R. King | I. Kaleel,<br>M.H. Nagaraj,<br>M. Petrolo,<br>E. Carrera | G. Li,<br>E. Jansen,<br>M. Cinefra,<br>E. Zappino,<br>R. Rolfes,<br>E. Carrera |

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# DYNAMIC HOMOGENISATION OF RANDOMLY IRREGULAR METAMATERIALS

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Metamaterials based on hexagonal periodic cells (honeycombs) have gained considerable attention in recent years. This can be an advanced material due to its capability of meeting high performance requirements in various critically desirable application-specific parameters [1]. These structural assemblies not only make an efficient use of material but are also characterized by interesting dynamic and wave propagation properties. A semi-analytical formulation has been developed for wave propagation in irregular honeycombs. Spatial structural irregularity of hexagonal lattices has been considered. There are few scientific literatures available concerning analysis of wave propagation in regular honeycombs [2]. However, due to inevitable uncertainties associated with manufacturing and service conditions, honeycomb lattices may not be always perfectly regular. The effect of spatially random structural irregularity in wave velocities of such irregular honeycombs will be discussed. Dynamic homogenisation of the metamaterials leads to some unusual properties such as negative elastic modulus at certain frequencies. New derivations are proposed to quantify and demystify such observations. s

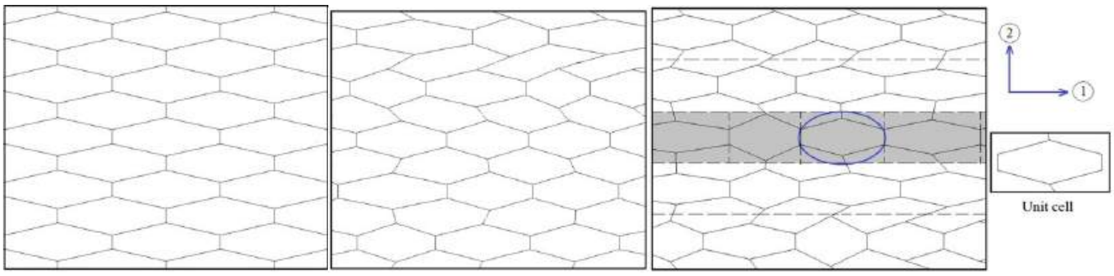


Figure 1 Irregular cellular metamaterials.

***References:***

1. Gibson L., Ashby M. F. (1999) Cellular Solids Structure and Properties. Cambridge University Press, Cambridge, UK.
2. Gonella S., Ruzzene M. (2008) Analysis of in-plane wave propagation in hexagonal and re-entrant lattices, Journal of Sound and Vibration 312 125–139

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# Multiscale Analysis of Photo-responsive Nanocomposites and Realization

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**Key words:** Photo Responsive Nanocomposite, Photoisomerization, Multiscale

Liquid crystalline polymers which contain photochromic chromophores can show macroscopic deformation under light irradiation. The light-induced shape change of the photo-responsive polymers (PRPs) is attributed to the *trans*-to-*cis*, or *cis*-to-*trans* isomerization of the mesogens, and it can be utilized to the microscale opto-mechanical actuators. However, it is difficult to analyze and precisely predict the deformation because the theoretical approach requires a comprehensive knowledge of broad, interdisciplinary physical regimes that range from photochemical reaction kinetics to manipulating continuum scale deformations. Here, we developed a new approach which integrates light input conditions, mesogen alignment, and continuum polymer deformations through sequential multiscale framework combining the Density functional theory, molecular dynamics, and finite element simulations. Also, the multiscale approach is applied to design the photo-mechanical behavior of the PRP nanocomposites with the consideration of the opto-mechanical coupling effect and microscopic interaction between the PRP matrix and fillers. This integrated framework can help to design the PRP and its composites.

## ACKNOWLEDGEMENT

This work was supported by a grant from the National Research Foundation of Korea (NRF), funded by the Korea government (MSIP) (No. 2012R1A3A2048841).

## REFERENCES

[1] Chung, H. and Choi, J. and Yun, J.-H. and Cho, M. Nonlinear photomechanics of nematic networks: upscaling microscopic behavior to macroscopic deformation. *Sci. Rep.* (2016) **6**:20026.

[2] Choi, J. and Chung, H. and Yun, J.-H. and Cho, M. Molecular dynamics study on the photo-thermal actuation of photo-responsive polymer reinforced by gold nanoparticles with size effect *ACS Appl. Mater. Interfaces* (2016) **8:** 24008–24024.

[3] Moon, J. and Choi, J. and Cho, M. Opto-mechanical behavior and interfacial characteristics of crosslinked liquid crystalline polymer composites with carbon nanotube fillers, Carbon (2017) ) **121:** 181-192.

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# Dielectric Breakdown Modelling in a Cracked Piezoelectric Solid

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When a cracked piezoelectric solid is placed in electric field, the high electric field will be induced both inside the crack and around the crack tip. If the local electric filed is enhanced to a critical level, dielectric breakdown (DB) may happen for gas inside the crack or for the solid around the crack tip. This talk will introduce the mechanism of gas and solid, discuss the effects of the DB, and finally present the results of field intensity factors or energy release rate before and after the DB.

# THERMO-ACOUSTIC RADIATION OF FREE-STANDING NANO-THIN FILM IN VISCOUS FLUID

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Thermo-acoustic (TA) effect did not attract very much attention in the past. Morse and Ingard [1] derived the coupled thermo-acoustic governing equations in 1968. In 2008, Xiao et al. [2] conducted thermo-acoustic experiment for carbon nanotube projectors in air and further in 2010, Aliev et al. [3] extended the work of Xiao [2] underwater. Hu et al. [4] put forward a theoretical explanation on thermo-acoustic emission of different kinds of sound source without taking the influence of heat capacity into consideration. Lim et al. [5] derived and presented thermo-acoustic wave generation for free-standing CNT thin film ignoring the viscosity of fluid. In this talk, further works on thermo-acoustic wave emission and propagation in viscous media are discussed. The fully coupled thermo-acoustic field is obtained for a free-standing nano-thin film in viscous fluid, which has been usually ignored in the previous works on thermo-acoustic interaction. The influence of heat loss, heat capacity and heat exchange is considered in this investigation. When a sinusoidal alternating current acts on the thin film, the double frequency effect can be determined easily. Subsequently, the thermal wave propagation is decoupled from the acoustic effect by improving the order of differential equations. Then, with appropriate simplification an analytical prediction is derived in which the attenuation coefficient and the classic expression are identical. In addition, the theoretical results agree well with experiment. Compared with Lim et al. [5], an analytical solution of higher-order accuracy is obtained. This work may be helpful to the design of the thermo-acoustic projectors that have shown great potentials for new underwater sonars compared with the electro-acoustic ones traditionally induced by membrane vibration.

# References

[1] Morse P. M. and Ingard K. U. Theoretical acoustics. *Princeton University Press*, 1968.

[2] Xiao L, Chen Z, Feng C, et al. Flexible, Stretchable, Transparent Carbon Nanotube Thin Film Loudspeakers. *Nano Letters*, 2008, 8(12), 4539-4545.

[3] Aliev A E, et al. Underwater Sound Generation Using Carbon Nanotube Projectors *Nano Letters*, 2010, 10(7), 2374-2380.

[4] Hu H, Zhu T and Xu J. Model for thermoacoustic emission from solids. *Appl. Phys. Let.*, 2010, 96(21), 214101.

[5] C.W. Lim, L.H. Tong and Y.C. Li Theory of suspended carbon nanotube thinfilm as a thermal-acoustic source. *J. Sound and Vib*, 2013, 332(21), 5451-5461.

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# A JOURNEY THROUGH COMPOSITE MATERIALS AND STRUCTURES: A PERSONAL RETROSPECTIVE

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This is a personal retrospective of the author's journey through mechanics of composite materials and structures over the last 42 years. Along the way the author has collaborated with a large number of students and colleagues, who have enriched his contributions to the subject. The authors work on the subject began with an association with Professor Charles Bert (University of Oklahoma), which paved the way for the author's professional journey through composite materials and structures. The publication of papers on third-order theory [1], layerwise theory [2], a book [3] on laminated composite plates, and founding a journal (Mechanics of Composite Materials and Structures now known under the title Mechanics of Advanced Materials and Structures) were the main milestones of the authors earlier works. In the second half of the authors career, he and his colleagues (students as well as fellow researchers) have developed least-squares-based finite element models of layerwise theory, finite element models of functionally graded plates and shells, and seven- and twelve-parameter shell theories and their finite elements for laminated composite structures. The author's recent research on nonlocal elasticity and couple stress theories in formulating the governing equations of functionally graded material beams and plates will also be discussed. In addition, the graph-based finite element framework (GraFEA) suitable for the study of damage in brittle materials will be discussed.

## References

[1] Reddy J.N., A simple higher-order theory for laminated composite plates, Journal of Applied Mechanics, 51, 745-752, 1984.

[2] Reddy J.N., A generalization of the two-dimensional theories of laminated composite plates, Communication in Applied Numerical Methods, 3, 173-180, 1987.

[3] Reddy J.N., Mechanics of Laminated Plates and Shells: Theory and Analysis, 2nd ed., CRC Press, Boca Raton, FL, 2004.

# Continuum Damage Modeling of Shear Postbuckling in Honeycomb Core

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Recently, the authors have highlighted by both numerical analysis and experiments the nonlinear behavior under shear of honeycomb [1]. The results showed that the buckling of the Nomex honeycomb core present a nonlinear elastic behavior beyond the buckling point. This is due to a reversible postbuckling as in aerospace structures. Depending on the load direction and the boundaries of the honeycomb the failure scenario is different. In classical tests such as double rail shear tests or double lap shear tests, the main loading direction is orthogonal to the cell edges at the vertex of the hexagonal shape. Thus, after a postbuckling regime, the honeycomb fails by collapse in shear of theses edges. Although for the tested specimen which mimics quite well the inserts in sandwich panels, the loading direction is parallel to this cell edges and the structures takes more easily the shear buckling thus generating a gain in the allowable up to 35 %. These observations allow the authors to propose a two parameters damage model to capture the shear nonlinear behavior of honeycomb cores. The first parameter will represent the initial buckling of the cells and the start of the collapse of the cells, this is from the initiation of the nonlinear behavior until the maximal shear stress. The second will represent the final collapse of the cells, this is from point where the maximal shear stress is reached until the shear stress is zero. Main results are shown below (the upper curve is the comparison with experiments and the two other represents the evolution of the damage parameters.

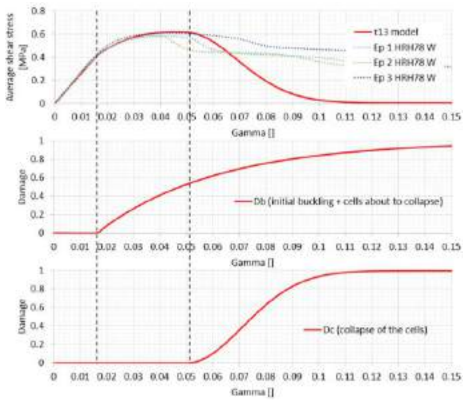


Figure 1 Comparison of the experimental curves of shear tests on the HRH-78 honeycomb and the model based on the damage laws..

*[1] Juan de Dios Rodriguez, Bruno Castanié, Christophe Bouvet, Experimental and numerical analysis of the shear nonlinear behavior of the Nomex honeycomb core: application to insert sizing. Submitted to composite Structures*

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# DYNAMIC RESPONSE EVOLUTION OF DAMAGED SLM LATTICE STRUCTURES

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Lightweight structures are very attractive for many fields of engineering where high strength and low mass are needed. At this purpose, recent technologies associated to powders micromelting (as SLM, selective laser melting) are used to fabricate lattice structures, characterized by variable and controlled density. Geometrical complexity and processes stabilization are the main issues to be considered in describing static behavior of lattices through homogenization methods, reduced order analytic models and full FE models [1-3]. Lattices have natural propensity to develop localized failures in correspondence to the numerous thin struts composing the texture. Then, even if the collapse of few cells has not appreciable effects on the global strength [4], the dynamic response may change and frequency shift processes may occur. These effects induce critical situations in some cases, as aerospace applications [5]. The experimental measurements reported in this paper provides the quantification of the free response evolution of SLM lattice structures under artificially-induced damage of the cellular texture. Analytic model based on concentrated parameters is also provided to predict the natural frequency shift. Ti6Al4V alloy samples, fabricated with EOS M290 and thermally treated, are used. Experimental setup includes instrumented impact hammer, accelerometer and data acquisition system.

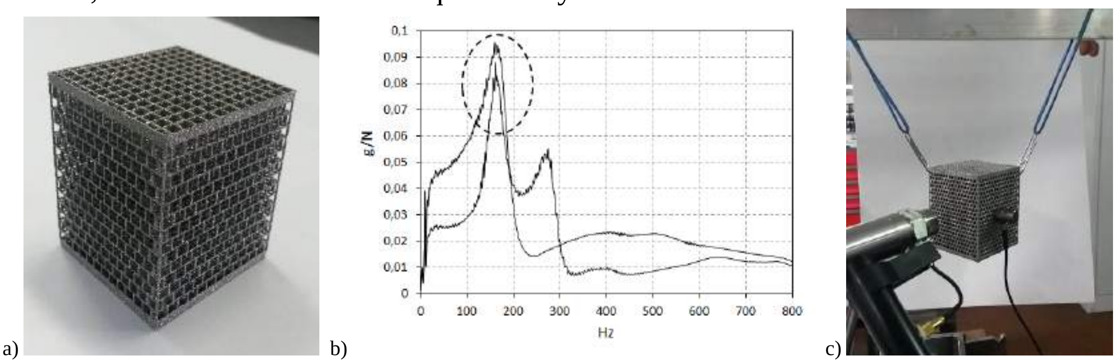

Figure 1. Lattice sample (a), experimental free response evolution (b) and experimental setup (c).

[1] Prager V. Introduction to structural optimization, Springer, 2017.
[2] Gibson L. and Ashby M. The mechanics of three-dimensional cellular materials, Royal Society, 1981.
[3] De Pasquale G. et al. Cellular structures from additive processes: design, homogenization and experimental validation. Sub. to Structural Integrity Procedia, 2017.
[4] De Pasquale G. et al. Experimental characterization of EBM and SLM cubic lattice structures for lightweight applications. Sub. to Experimental Mechanics, 2017.
[5] Aerospace: RUAG - Additive Manufacturing of Satellite Components (available online at: https://www.eos.info/case_studies/additive-manufacturing-of-antenna-bracket-for-satellite)

# NONLOCAL THEORY OF PLATES, SHELS AND BEAMS. HIGHER ORDER, TIMOSHENKO'S AND EULER-BERNOULLI MODELS

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Experimental researches at nanoscale demonstrate that the mechanical properties of nanodimensional materials are very influenced by "size effects" or "scale effects". Over the past decade, the non-local elasticity theory (non-local mechanics) has emerged as a widely promising size-dependent continuum theory.

The nonlocal continuum mechanics assumes that the stress at a point is a function of strains at all points in the continuum. Such theories contain information about the forces between atoms, in addition the internal length scale is introduced into the constitutive equations as a material parameter. The theories of nonlocal continuum are created by Eringen and then further developed by other researchers and reported in numerous publications.

In this presentation higher order, Timoshenko's and Euler-Bernoulli models of shells, plates and beams based on nonlocal theory of elasticity have been developed and compared. For strait simply supported beam of the length $2l$ subjected to the sinusoidal load analytical solution can be easily calculated and can be presented in the analytical form.

For the first order theory

$$u_2^0(x_1)=\frac{(4+(\pi e_0 a)^2)(12\mu+\pi^2h^2(\bar{\lambda}+2\mu))\cos(\pi x_1/2)}{\pi^4\mu EJF},\quad u_1^1(x_1)=\frac{6(4+(\pi e_0 a)^2)\sin(\pi x_1/2)}{\pi^3 h(\bar{\lambda}+2\mu)}$$

For the Timoshenko's theory

$$u_2^{Tim}(x_1)=\frac{(4+(\pi e_0 a)^2)(\pi^2EJ-4F\mu)\cos(\pi x_1/2)}{\pi^4\mu EJF},\quad \gamma_1(x_1)=\frac{2(4+(\pi e_0 a)^2)\sin(\pi x_1/2)}{\pi^3 EJ}$$

For the Euler-Bernoulli

$$u_2^{Eul}(x_1)=\frac{4(4+(\pi e_0 a)^2)\cos(\pi x_1/2)}{EJ\pi^4}$$

Figure 1 shows deflection of the beam calculated using these equations for the following data $e_0a/l=0.1$ and $e_0a/l=0.3$ respectively. The presented results have been normalized by the value $u_2^{Eul}(0)$ for the $e_0a/l=0.0$, which to correspond local theory.

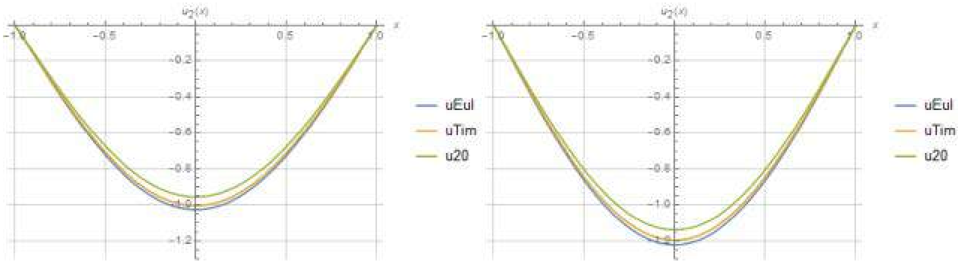


Figure 1. Deflection of the beam versus normalized length

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# BUCKLING OF AND WAVE PROPAGATION IN FUNCTIONALLY GRADED DIELECTRIC ELASTOMERIC HOLLOW CYLINDERS

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This study considers the instability of and wave propagation in a soft circular hollow cylinder (or cylindrical shell) composed of functionally graded dielectric elastomeric (FGM-DE) material subjected to inner/outer pressure, axial stretch as well as axial or radial electric field. The problems are tackled with the state-space formalism, which is established on the basis of the linearized incremental theory for a superimposed infinitesimal deformation of a deformable continuous body with electromechanical coupling. To this end, the general nonlinear electroelasticity theory also should be invoked. Analytical characteristic equations are derived for both the instability and wave propagation problems, for which the approximate laminate model is also adopted. Comprehensive numerical results are obtained for a pressurized soft FGM-DE hollow cylinder, of which the material behavior following the generalized incompressible Mooney-Rivlin model. The effects of material gradient, pressure difference, electric stimulus, and axial pre-stretch are investigated. It is found that the buckling and wave propagation behavior of soft FGM-DE cylindrical shells can be actively changed by adjusting the related parameters.

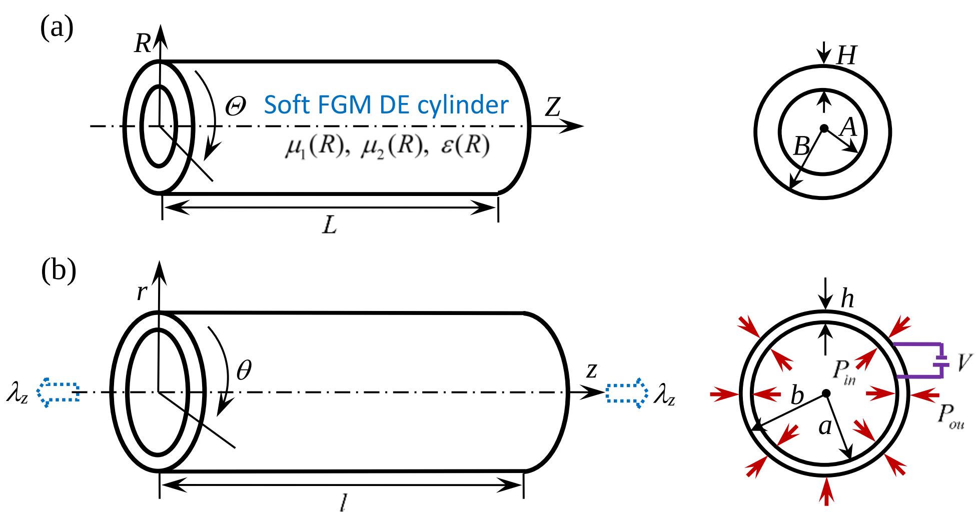


Figure 1 A soft FGM DE cylinder under various external stimuli.

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# Characterization of the effect of adding titanium dioxide on the hydroxyapatite deposited on the 316 L substrate for biomedical application

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Hydroxyapatite (HAp) ($Ca_{10}$ $(PO_4)_6$ $(OH)_2$) is a bioactive ceramic widely used in surgery for the replacement of hard tissue because of its resemblance to the mineral composition of natural bone. However, because of its fragility, its applications in the orthopedic and dental field are limited
So our study consists to investigate the effect of the addition of TiO2 inner-layer on the morphological and mechanical properties of hydroxyapatite (HAP) bioceramic coatings deposited on 316L stainless steel by sol-gel method in order to improve their properties of hydroxyapatite and expand its clinical application. The addition of TiO2 as sub-layer of a hydroxyapatite coating results in changes in surface morphology as well as an increase of the microhardness. . The deposition of the inner-layer provides the formation of new types of hydroxyapatite coatings at the same condition of annealing. This represents an advantage for the various applications of the hydroxyapatite bioceramic in the medical field. Classical hardness measurements conducted on the coated systems under the same indentation load (10g) indicates that the microhardness of the HAP coating is improved by the addition of TiO2 inner-layer on the 316L stainless steel substrate. The hardness values obtained from both classical tests in microindentation and the continuous stiffness measurement mode in nanoindentation are slightly different. This is because nanoindentation is more sensitive to the surface roughness and the influence of defects that could be present into the material. Moreover, nanoindentation is the most useful method to separate the contribution of each layer in the bilayer coatings. In this study, the hardness is comparable with those reported previously for pure HAP ceramics (1.0–5.5 GPa) which are close to those properties of natural teeth.

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# TIME FRACTIONAL VIBRATION OF MAGNETO-HYPERELASTIC THIN DISC

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This study investigates anomalous vibration of electrically conducting thin disc in the presence of externally applied magnetics field. The disc is made of hyperelastic John's material and its mechanical response is given by the Piola-Kirchhoff's stress tensor which is energy conjugate to the gradient of deformation. The electro-magneto-elasticity problem under consideration is described by modified equation of motion, Maxwell's equations of electromagnetism and generalized Ohm's law. Invoking the constraints of plane stress and radial deformation on stress and deformation fields respectively, the governing equations are reduced to fractional integro-differential equations which in-turn yield fractional nonlinear wave equation. It is observed that the presence of a parameter characterizing the mechanical-electromagnetic interaction of the material of the disc induces nonlinearity in the wave equation. Furthermore, the radial-circumferential stresses relation in the hyperelastic disc generalizes the well-known result in classical elasticity theory. In the absence of externally applied magnetics field, the obtained fractional nonlinear wave equation reduces to some fractional linear wave equation in literature; and as the order of fractional derivative tends to 2, the resulting wave equation approaches the classical wave equation. Approximate solution of the fractional nonlinear wave equation is presented using Adomian decomposition approach and conformable fractional derivative. Finally and amongst other things, this work shows that conformable fractional derivative is efficient for solving fractional nonlinear differential equation.

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# STUDY OF VIBRATION ANALYSIS OF MICROSTRETCH THERMOELASTIC RECTANGULAR PLATE

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In this article, the closed form expressions for the transverse vibrations of a homogeneous isotropic micropolar microstretch generalized thermoelastic thin rectangular plate based on Kirchhoff theory have been derived. The effects of thermal relaxation times, microstretch parameters, surface conditions and plate dimensions on energy dissipation induced by thermoelastic damping in MEMS resonators are investigated. The axial ends of the plate are assumed to be at either clamped or simply supported conditions. Analytical expressions for deflection, microstretch function, temperature distribution and thermoelastic damping have been obtained. The numerical simulation has been carried out with the help of MATLAB software for magnesium like material. The computed results have been presented graphically for distinct considered values of thickness and length as well. The obtained analytical results are envisioned to be easy to implement for engineering analysis and designs of resonators, actuators.

**Keywords:** Plate; Microstretch; Thermoelastic Damping; Clamped; Simply Supported

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# CRACK ANALYSIS IN MAGNETO-ELECTRO-ELASTC SOLIDS BY GRADIENT THEORY

J. Sladek[1,*], V. Sladek[1], M. Wünsche[1]

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The paper presents a computational method to analyse 2-d in-plane crack problems in magneto-electro-elastic (MEE) solid described by the gradient theory with the direct flexoelectric effect. A physically similar, but simpler, problem has been analyzed very recently by the authors for nano-sized cracks in piezoelectric material (Sladek et al. 2017). Although great success has been made for MEE materials with macroscopic characteristic dimensions, applications of the conventional elastic theory in the nanoscale are not accurate because the size effects on the mechanical properties of materials may be prominent at the nanoscale. The gradient elasticity theory is also suited for studying the strain and stress fields near the crack-tip at the microscale due to the large strain and stress gradients in its vicinity. Mao and Purohit (2015) have analyzed the stress and polarization fields near point defects, dislocations and cracks in flexoelectric solids. They have shown that flexoelectricity plays an important role in the immediate vicinity of these defects where there are large strain gradients.

In this study the size-effect is considered by including the strain gradients in the constitutive equations of a magneto-electro-elastic material. The problem with strain gradients is quite complex and an appropriate computational tool is required to obtain accurate solutions. The variational principle is applied to derive the governing equations with the corresponding boundary conditions in MEE solid. The FEM formulation is developed from the governing equations. The $C^1$-continuous elements are applied to guarantee the continuity of variables and their derivates in the element boundaries.

The higher-order *J*-integral and the energy release rate for fracture mechanics analysis in strain-gradient piezoelectricity (Sladek et al. 2017) is extended here for magneto-electro-elastic materials. Finally, numerical examples are performed to compare the results obtained by the gradient theory with those obtained by classical theory.

## References

Sladek, J., Sladek, V., Stanak, P., Zhang, Ch., Tan, C.L. (2017) Fracture mechanics analysis of size-dependent piezoelectric solids. Int. J. Solids Struct. 113: 1-9.

Mao S., Purohit P.K. (2015) Defects in flexoelectric solids. J. Mech. Phys. Sol. 84: 95-115.

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# ADVANCED DESIGN RULES FOR RING-STIFFENED SHELLS SUBJECT TO AXIAL COMPRESSION

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The cylindrical shell subject to uniform axial compression has been studied for over 100 years now. Purely mathematical studies in the early 1900s were followed by intensive experimental research until the 1990s. The demand for faster air craft and ships as well as the rising interest in astronautics lead researchers to the exploration of stiffened shells to save weight and to design more efficient structures. Amongst the advanced shell structures in focus was the ring-stiffened shell which received a lot of attention especially in the 1960s and early 1970s. Neither theoretical nor extensive experimental research has been conducted ever since because grid-stiffened shells promised better bearing capacity for typical air craft and ship structures.

However, in building construction, ring-stiffened shells are built in a huge variety since they offer a superior resistance against lateral loads such as wind or external pressure. The trend towards light-weight structures ultimately leads to constructions where even small axial compressional forces, e.g. from dead weight or wind, may cause a failure of tanks and silos.
The experimental studies in the 60s and 70s showed that ring-stiffeners may greatly enhance the resistance against axial buckling. However, since there is a lack of appropriate design rules, this beneficial effect may not be taken into account when a tank, silo or pipe is designed.

To overcome this unfavorable circumstance, experiments from literature are evaluated, serving as the basis for a numerical study on ring-stiffened shells subject to axial compression. The case-dependent reduction factors are transformed into a design format using the modern Eurocode 3-1-6 frame work. It is shown that appropriately chosen parameters of the buckling curve may lead to safe but, especially for thin-walled shells, more economical structures compared to earlier provisions of this standard.
The strength gain of closely and widely ring-stiffened shells compared to unstiffened cylinders is quantified, showing the clear advantages of the ring stiffening.
Since the design equations are dependent on the imperfection amplitude, it is possible to take into account different qualities of fabrication. By comparing the outcome of experiments with the imperfection amplitude dependent calculated bearing capacities of the structures in focus, an extraction of proposed imperfection depths related to the geometrical parameter r/t is possible.

It is shown that design procedures may be deduced from sophisticated numerical analysis. However, a calibration against test results is always necessary to maintain safety and is useful to optimize efficiency.

# AN INVARIANT-BASED DESIGN OF CFRP LAMINATES

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Carbon Fiber Reinforced Polymer (CFRP) composites have become the material of choice for applications requiring superior specific strength and stiffness combined with corrosion resistance. However, the inherent anisotropy of these materials makes their mechanical characterization rather complex, costly and time consuming. In addition, the design optimization solution of a composite structural component is typically material specific. This work discusses an invariant-based design procedure for CFRP laminates using trace-normalized plane stress stiffness matrix and unit circle failure criterion (Figure *1*). Using the approach proposed, the optimal stiffness-based layup solution is valid for any CFRP. Once the general stiffness-based optimal solution is determined, trace of the plane stress stiffness matrix is the only elastic material property required. Design for strength is carried out based on the unit circle failure criterion, which is invariant with respect to ply orientation and requires only the unidirectional longitudinal tensile and compressive strains-to-failure. The invariant-based design approach was applied to smooth and open-hole plates and compared to the traditional design approach. It was demonstrated that testing for material characterization and the design procedure of CFRP structural components could be greatly simplified.

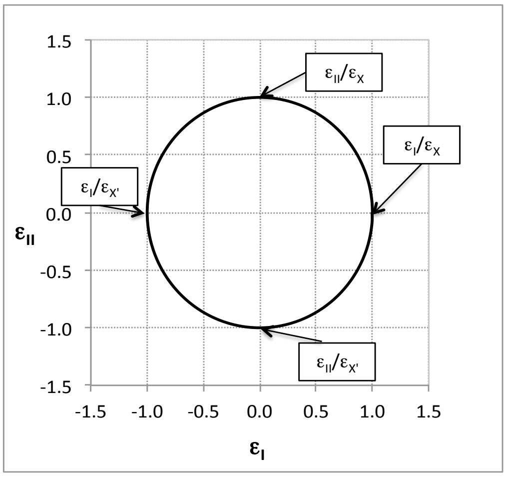


Figure 1 Unit circle failure envelope.

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# THERMODYNAMICALLY CONSISTENT BEAM THEORIES IN CONTEXT OF CLASSICAL AND NON-CLASSICAL CONTINUUM MECHANICS

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**Abstract**

The paper presents small deformation, small strain beam theories using thermodynamic principles of classical/non-classical continuum mechanics. It is shown that thermodynamically consistent beam theories cannot be derived using classical continuum mechanics in which only material point displacements are considered as degrees of freedom at a material point. In the thermodynamically consistent beam theories it is necessary to consider non-classical mechanics. It is shown that consistent beam theories can be derived using material displacements and: (i) internal rotations due to antisymmetric part of displacement gradient tensor (ii) and/or additional Cosserat rotations acting about the same axes of the same triad at a material about which the internal rotations are defined. Different choices of these rotations lead to different beam theories. In this paper we only consider thermoelastic behavior. Euler-Bernoulli, Timoshenko, Reddy, and Levinson existing beam theories are considered to illustrate their thermodynamic consistency or lack of it. Solutions of model problems are presented to further illustrate the merits of the consistent beam theories presented here and the solution from these theories are compared with those obtained using currently used theories.

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# CONSISTENT THERMOVISCOELASTIC BEAM THEORIES WITHOUT MEMORY IN CONTEXT OF CLASSICAL AND NON-CLASSICAL CONTINUUM MECHANICS

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**Abstract**

This paper presents thermoelastic beam theories with dissipation mechanism derived strictly using conservation and balance laws of non-classical continuum mechanics and the constitutive theories derived based on integrity using the conditions resulting from the entropy inequality. It is shown that consistent beam theories with nonphenomenological dissipation mechanism cannot be derived using classical continuum mechanics as the non symmetry of Cauchy stress tensor, existence of Cauchy moment tensor and necessity of additional balance law are essential requirement for the thermodynamic consistency of these theories. The constitutive theories presented in this paper are ordered rate theories, hence contain more comprehensive mechanism of elasticity and dissipation. Model problem studies are presented to illustrate the merits of this work. The beam theories presented in this paper are compared with currently used theories to further highlight various features of the theories presented here.

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# THERMOVISCOELASTIC BEAM THEORIES WITH MEMORY IN CONTEXT OF CLASSICAL AND NON-CLASSICAL CONTINUUM MECHANICS

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## Abstract

This paper presents a thermodynamically consistent thermoviscoelastic beam theory with dissipation and memory. It is shown that the derivation of consistent thermoviscoelastic beam theory requires principles of non-classical continuum mechanics in which: (i) rotational degrees of freedom are permitted (ii) Cauchy stress tensor is non symmetric (iii) Cauchy moment tensor exists and (iv) additional balance law(s) are permitted. Rotational degrees of freedom could be due to antisymmetric part of the displacement gradient tensor and/or due to additional unknown Cosserat rotations. Different choices of these lead to different beam theories. In the present work the use of the conservation and balance laws of non-classical continuum mechanics are shown to be essential for consistent theories. The constitutive theories are rate theories incorporating higher order derivatives of the strain tensor and the rotation gradient tensor. It is shown that the mechanisms of dissipation and memory in such theories are due to Cauchy stress tensor as well as Cauchy moment tensor. Model problems are considered and their solutions are presented to further illustrate the strengths of the present work. Retardation moduli are derived and the existence of relaxation moduli is discussed.

# THE USE OF PERIDYNAMICS IN THE STUDY OF CRACK PROPAGATION IN SOLID MATERIALS

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Peridynamic-based computational tools are finding an increasing use in computational mechanics whenever crack propagation problems have to be solved. Peridynamics (PD) is a nonlocal continuum mechanics theory which overcomes the limitations of classical continuum mechanics in the description of problems affected by discontinuities. The high computational cost is the main weak point of PD-based software: the nonlocal nature of PD causes every point of a discretized domain to interact with a large number of other points and consequently the many interactions of each point require an large number of numerical computations.

The present contribution will describe the main recent results in the attempt to develop more efficient computational tools that exploit the advantages of PD without being hampered by its pitfalls.

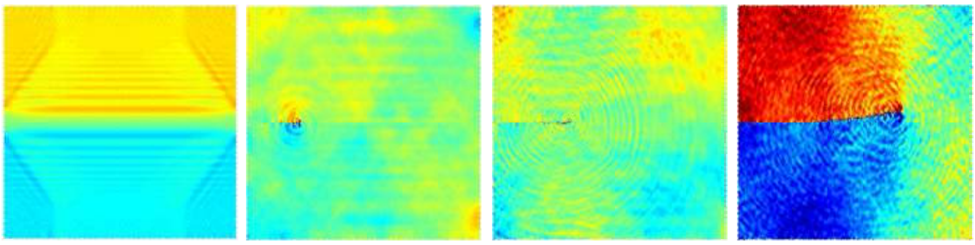

Figure 1 Contour plots of the vertical velocity component at different time instants in a plate loaded in the vertical direction along the top and bottom edges.

A first way to increase the efficiency of PD-based computational methods is to couple them with faster methods based on classical continuum mechanics, such as the finite element method. However PD-FEM coupling is not straightforward and may introduce some spurious effects, in particular in dynamic conditions.

Another possibility to reduce the computational burden of PD-based algorithms is provided by the introduction of PD discretizations with variable horizon. The most commonly adopted discretized formulation of PD makes use of uniform grids in such a way that the most stringent requirement for grid density, usually due to local effects, determines the grid density in the whole domain. Adopting a variable grid size can greatly reduce the cost of the computations.

A series of static and dynamic examples will be presented to illustrate the most recent contributions of the authors.

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# Homogenization of nonlinear highly heterogeneous shell

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From now the theory of homogenization for highly heterogeneous three dimensional structures is well established. It is not the same for theory of homogenization of highly heterogeneous thin structure (beam, plate or shell). Fom now the best mathematical theory is presented by Caillerie [1] and Kohn and Vogelius [2]. These models are mathematically elegant and rigorous but only related to a simple engineering model (the Kirchhoff plate model). But the most important problem results from *a priori* scalings, assuming applied loads (or deformation) be of certain orders of shell thickness. In reality applied loads are external, which should not be directly related to the thickness in various situations. Results for homogeneous thin structures suffer from the same drawback.

The aim of this work is to propose a multiscale finite-strain shell theory for simulating the mechanical response of highly heterogeneous shell with varying thickness. To resolve this issue a higher-order stress-resultant shell formulation based on multiscale homogenization is considered. At the macroscopic scale level, we approximate the displacement field by a fourth-order Taylor-Young expansion in thickness. We take account of the microscale fluctuations by introducing a boundary value problem over the domain of a three-dimensional representative volume element (RVE). For the sake of simplicity, the microstructure is assumed to be periodic with respect to curvilinear coordinates. The RVE is subjected to body force and stress vectors acting on both the upper and lower faces. Then this load act obviously on the macroscopic through the local scale. The geometrical form and the dimensions of the RVE are determined by the representative microstructure of the heterogeneity. In this way, an in-plane homogenization is directly combined with a through thickness stress integration. As a result the macroscopic stress resultants are obtained from microscopic stress through a specific form the macro-micro Hill-Mandel condition (which expresses the equivalence between both the internal macroscopic and microscopic energies). All microstructural constituents are modeled as first-order continua and three-dimensional continuum, described by the standard equilibrium and the constitutive equations. This type of theory is anxiously awaited.

[1] Caillerie, D. Thin elastic and periodic plates. *Math. Models Methods Appl. Sci.* 1984; 6 : 159–191.

[2] Kohn, RV, and Vogelius, M. A new model for thin plates with rapidly varying thickness. *Int. J. Solids and Struct.* 1984; 20 : 333–350.

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# INDUSTRIALIZATION OF A KINEMATIC VIBRATION ENERGY HARVESTER FOR SMART BEARING WITH PIEZOELECTRIC/MAGNETIC COUPLING

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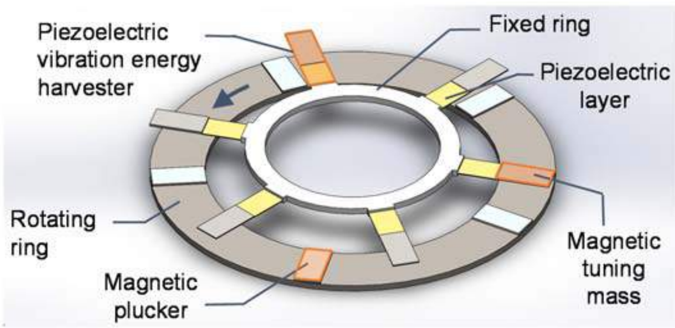
An innovative configuration to equip monitoring and sensor devices with a local power supply is currently investigated in the literature, by resorting to some kinematic energy harvester, more than to pure vibration energy conversion [1]. A kinematic rotational scavenger resorts to relative rotation between machine components, to exploit a dynamic excitation induced upon a flexible smart structure. Particularly, some benefits of the electromechanical plucking effect provided by interaction between permanent magnets were explored, when they are applied to flexible structures, with surface bonded piezoelectric layers. In case of smart bearing for industrial application [2], a prototype of cantilever piezoelectric beam, clamped to fixed ring, and excited at its tip by interaction between a permanent magnet locally bonded and another one, connected to the rotating ring, is currently developed. After a preliminary evaluation of system performance, the industrialization of this hybrid piezoelectric/magnetic energy scavenger needs to explore some key issues of design.



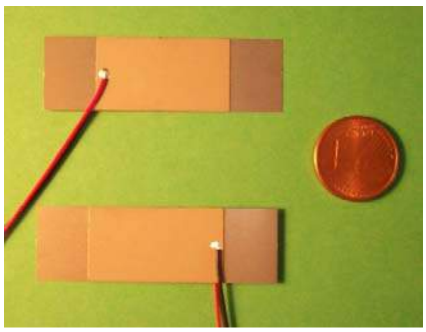



Figure 1 Concept and prototypes of rotational piezoelectric vibration energy harvester plucked by permanent magnets.

The number of smart cantilevers and magnets distributed along circumference of fixed ring must be assessed by precisely predicting the amplitude of dynamic excitation, for given gap between magnets and spin speed of rotating ring. This implies a detailed analysis of magnetic coupling in presence of cantilever vibration and ring rotation.

The layout of piezoelectric layer must be optimized by considering the structural modes involved in the electromechanical coupling, for given angular velocity of ring, depending upon the service conditions of bearing. Particularly, a choice between manufacturing twin

# MODAL ANALYSIS OF TEMPERATURE-DEPENDENT FG CARBON NANOTUBE-REINFORCED COMPOSITE PLATES IN THERMAL ENVIRONMENT

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The present investigation deals with the modal characteristics of carbon nanotube-reinforced composites (CNTRCs) in thermal environment. The CNTRCs are considered made up of four different types of uniaxially aligned reinforcements. More specifically, uniformly distributed and three different types of functionally graded distributions. The materials are temperature-dependent and their effective properties are derived by using a micromechanical model. The governing equations (GEs), in their weak-form, are derived by using Hamilton's Principle in conjunction with hierarchical plate models. The Ritz

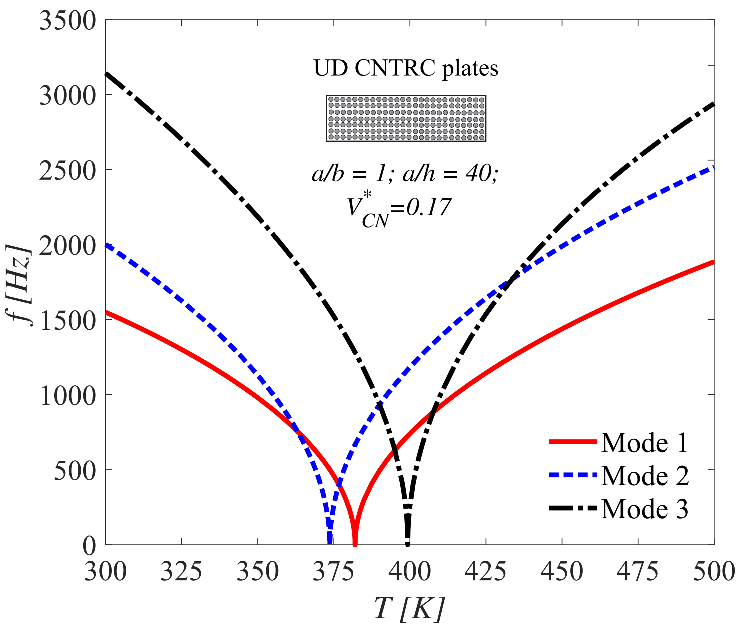


Figure 1: Effect of the thermal environment on the first 3 modes of a simply supported UD CNTRC plate with temperature-dependent materials.

method, based on efficient trigonometric trial functions, is employed to solve the GEs. Convergence and stability of the proposed formulation have been thoroughly analyzed by assessing several higher-order plate models. The effect of significant parameters such as length-to-thickness ratio, volume fraction index, CNTRCs typology, boundary conditions as well as temperature on the modal characteristics is discussed.

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# BAND-GAP PROPERTIES OF PHONONIC CRYSTAL BEAMS WITH FLUID-SOLID COUPLING

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We experimentally and numerically investigate the band-gap evolutions of a fully or partially submerged phononic crystal (PC) beam with fluid-solid coupling. We first study the influence of the hydrodynamic loading on the band-gap and transmission properties of the PC beam. The displacement transmissions of the submerged PC beam are directly measured by a fiber Bragg grating (FBG) displacement sensing system. Good correspondences between the experimental and numerical results are obtained. We demonstrate that the fluid-solid coupling for PC beams can largely lower the band gaps. Note that our results also indicate that excellent dynamic sensing performance can be obtained even when the proposed FBG sensors are totally immersed in water.

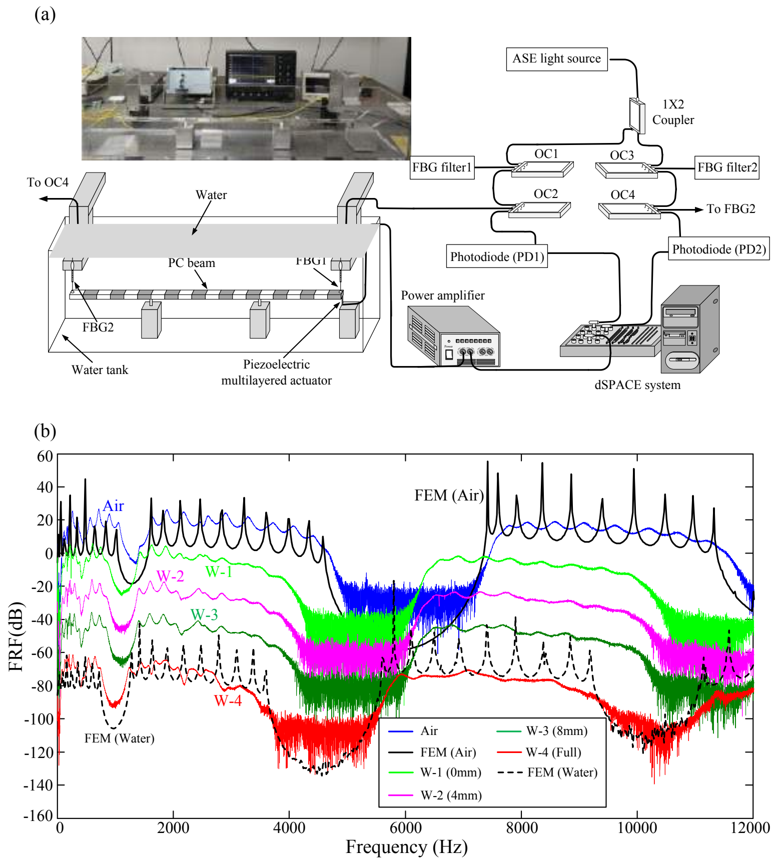


Figure 1 (a)Experimental setup; (b) Band-gap evolutions through fluid-structure interaction.

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# FINITE ROTATION EXACT GEOMETRY SHELL ELEMENT FOR 3D STRESS ANALYSIS OF COMPOSITE STRUCTURES

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The paper presents a robust nonlinear exact geometry or geometrically exact (GeX) four-node solid-shell element utilizing a method of sampling surfaces (SaS). The term GeX reflects the fact that the parametrization of the middle surface is known and, therefore, coefficients of the first and second fundamental forms and Christoffel symbols are taken exactly at element nodes. The SaS method is based on choosing inside the *n*th layer $I_n$ SaS parallel to the middle surface in order to introduce the displacements of these surfaces as basic shell unknowns. Such choice of unknowns with the consequent use of Lagrange polynomials of degree $I_n - 1$ in assumed approximations of the displacements and strains through the thicknesses of layers yields the efficient higher-order shell formulation. The inner SaS are located inside each layer at Chebyshev polynomial nodes that makes it possible to minimize uniformly the error due to Lagrange interpolation. As a result, the GeX/SaS shell formulation can be applied to obtaining the numerical solutions for laminated composite shells, which asymptotically approach the 3D exact solutions of elasticity as the number of SaS tends to infinity.

The Green-Lagrange strain tensor of the GeX/SaS shell formulation is objective, i.e., it exactly represents arbitrarily large rigid-body shell motions in any curvilinear coordinate system. The finite element formulation developed is based on the hybrid-mixed method that allows the use of loading increments, which are much larger than possible with the displacement-based solid-shell element formulations. Moreover, the tangent stiffness matrix is evaluated through 3D analytical integration and its explicit form is presented.

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# Vibrations of functionally graded graphene reinforced porous nanocomposite cylindrical shells

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Graphene possesses high Young's modulus and high strength, making it a promising nanoreinforcement to improve mechanical properties of conventional polymer, metal, and ceramic materials. Graphene reinforced nanocomposites have attracted tremendous interests due to their potential applications in engineering fields as high strength and light weight structural materials. Introducing the graphene into porous materials is a practical way to strengthen their mechanical properties and maintain their potential for lightweight structures, simultaneously.

Vibration characteristics of novel functionally graded porous nanocomposite cylindrical shells reinforced with graphene nanoplatelets (GPLs) are studied where the weight fraction of GPLs and the porosity coefficient of pores vary through the thickness direction. Both the GPL patterns and porosity distributions with three different types are considered. The mechanical property of closed-cell cellular solids is employed to determine the variation of Poisson's ratio and the relation between the porosity coefficient and the mass density. Using the Donnell's shell theory, governing partial differential equations of motion for the nanocomposite cylindrical shell are formulated.

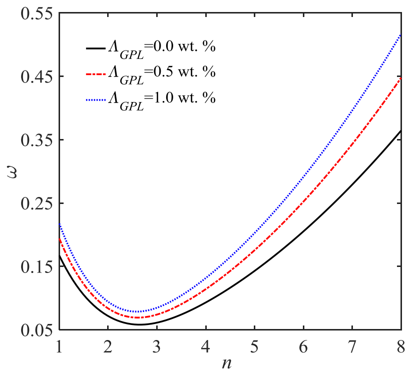

Figure 1 Effect of GPL weight fraction on natural frequencies of the shell

Parametric studies of weight fractions, geometrical sizes and distribution patterns of GPLs, the porosity coefficient and travelling wave numbers on the natural frequency for the nanocomposite cylindrical shell are conducted. Results show that the frequencies of the cylindrical shell can be significantly increased by adding small amounts of graphene into the metal matrix. GPLs with a larger surface area but less single graphene layers are preferred nanofillers as they offer the best structural performance of porous nanocomposite cylindrical shell.

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# MODE SHAPE VARIATIONS OF THICKNESS-SHEAR VIBRATIONS OF QUARTZ CRYSTAL PLATES IN A THERMAL FIELD

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It has been generally known that the presence of a thermal field will cause variations of vibrations of quartz crystal plates through frequency and mode shapes of quartz crystal resonators. Sometimes the mode shape variation will be serious enough to cause mode conversion and consequently the resonator will be in a critical state of failure known as activity dip. It has been proven that vibrations of quartz crystal plates in the thickness-shear mode can be well described by the theory of incremental thermal field in conjunction with the Mindlin plate equations, demonstrating the possibility that vibration frequencies and mode shapes can also be well described with the temperature as an active variable. By studying the vibrations with temperature changes in a given operating range, we calculated the frequencies and vibration modes as a function of temperature, then using them for the calculation of vibration energies including both strain and kinetic energies for vibration mode identification or characterization based on energy composition and changes.

Through these steps, we can clearly observe the trend of changes of vibration frequency, amplitudes, and vibration energy with temperature change, thus making it possible for the changes of vibrations and particularly the weakening or enhancement of the dominance of particular vibration modes. With such relations known, we can examine the selected design and consider modifications of design parameters to restrict the variation of certain vibration parameters to maintain the superior performance of quartz crystal resonators. We also need to develop analytical tools for the evaluation of such variation so the optimal design without significant mode change or occurrences of mode conversion in a given frequency range can be achieved.

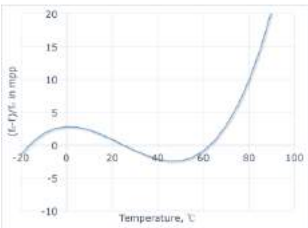


Fig. 1 Frequency-temperature curve of the fundamental thickness-shear vibrations of AT-cut rectangular plate ($a/b$ = 32. 9148).

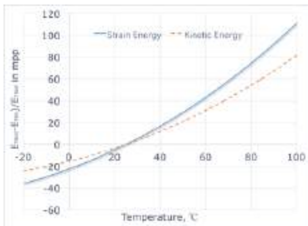


Fig. 2 Energy distribution change of the thickness-shear mode versus temperature for AT-cut rectangular plate ($a/b$ = 32. 9148).

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# A GEOMETRY-BASED METHOD FOR 3D TOPOLOGY OPTIMIZATION

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This work focuses on an innovative Topology Optimization (TO) strategy to design 3D structures in the framework of the *Solid Isotropic Material with Penalization* (SIMP) method. The computation domain, wherein the structure is embedded, is described through Finite Elements (FE) and a fictitious density function, defined at the centroids of the mesh elements. Lower and upper bounds of the pseudo-density identify the "void" and "solid" phases, respectively. A penalization of meaningless intermediate densities is employed to provide a well-defined void-material design. Although the standard SIMP method constitutes the basis of TO commercial software (e.g., Altair-OptiStruct), it presents some drawbacks: firstly, the final design is not CAD-compatible; thus, a time-consuming CAD reconstruction phase is necessary. Secondly, the number of design variables, being equal to the number of the underlying elements, could be significant for 3D problems. Finally, suitable filtering techniques must be considered in order to avoid physically meaningless checker-board configurations.

The proposed strategy aims at overcoming these issues: the fictitious density field of the SIMP method is described by means of a 4D NURBS hypersurface, i.e., a geometric CAD-compatible entity. Therefore, the topology description is now unrelated to the mesh and the NURBS hypersurface constitutes a well-defined geometric parametrization of the computation domain. In this background, the 4D NURBS can be exploited for both the formulation of optimization constraints and the CAD reconstruction phase. The new design variables are the NURBS control points coordinates and weights. Through the proposed approach, the number of design variables can be reduced and a filter zone is implicitly provided thanks to the *local support property* of the NURBS basis functions. An example of compliance minimization with an equality volume constraint is proposed and a qualitative comparison between the NURBS-based and the standard SIMP method is shown.

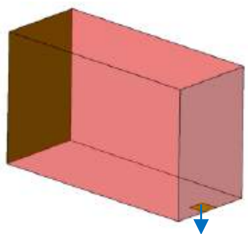

Figure 1 Clamped beam example: reference domain

Figure *2* NURBS-based SIMP solution

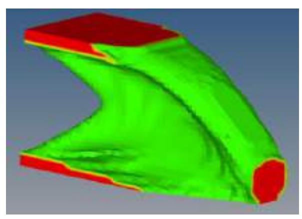

Figure 3 Altair OptiStruct solution

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# Multi-scale optimization of lattice structures for biomechanical components

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In this work a general multi-scale optimization methodology for designing lattice structures for biomechanical components is presented. The proposed approach is based on the one hand upon a general numerical homogenization scheme and on the other hand on the non-uniform rational basis spline (NURBS) curves formalism to represent the shape of the branches of the representative volume element (RVE) of the lattice at the lower scale. The optimum configuration of the lattice will be suitable for additive manufacturing processes in respect of specific technological constraints.

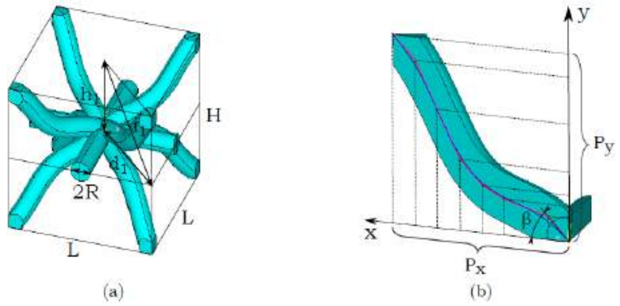


Figure 1 (a) overall size of the lattice RVE and (b) the local geometric design variables of the oblique branches.

The design problem is formulated as a constrained non-linear programming problem (CNLLP). The goal is to find the optimum shape of the RVE minimizing the lattice overall mass and satisfying a set of requirements of different nature without introducing simplifying hypotheses. These requirement are taken into account in the form of optimization constraints and include: (1) mechanical constraints on the effective elastic properties to ensure the positive definiteness of the stiffness tensor of the equivalent homogeneous material at the macroscopic scale; (2) a mechanical requirement on the first buckling load of the lattice RVE; (3) manufacturing constraints on the admissible ratio between the local curvature radius and the thickness of the lattice branches.

The effectiveness of the approach is proven by calculating the response of a femoral lattice prosthesis under static load. The lower computational effort with respect to full-FEM approach is clearly demonstrated. Finally, the numerical homogenization is used to validate experimental results of previous works in terms of force-displacement relationships of light-alloys lattice samples with cubic cells. In this case, the influence of border effects and cells number is investigated as well as technological process tolerances.

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# An experimental validation of the effectiveness of quasi-trivial solutions for composite laminates

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In this work the problem of the least-weight design procedure of a multilayer composite plate is addressed. The proposed design method is based on an optimization strategy that uses neither simplifying hypotheses nor standard rules for determining the optimum stack. Indeed, the design task is stated as a constrained non-linear programming problem (CNLPP) wherein requirements of different nature are integrated as optimization constraints. Such constraints include mechanical requirements (i.e. material properties, first buckling load of the plate, membrane stiffness) together with geometrical and technological restrictions on the selected design variables.

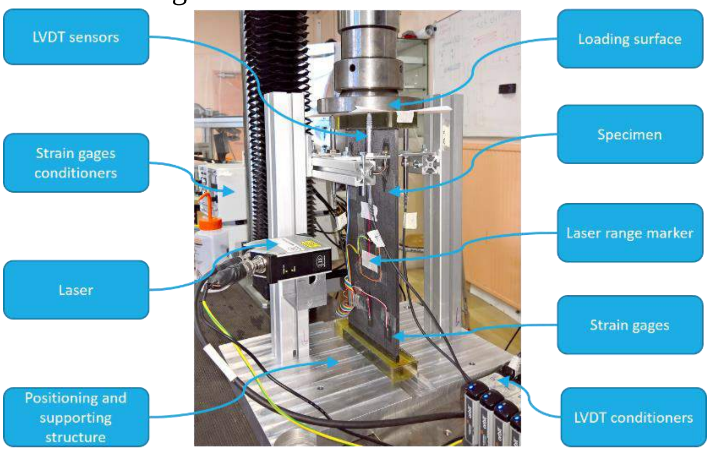

Figure 1 Set up of the experimental apparatus for buckling analysis.

The proposed strategy follows a two-step approach which first selects the optimum number of plies and then searches the optimum stack in the space of the so-called *quasi-trivial* solutions.

The quasi-trivial optimum sequences have been compared with stacking sequences developed following layup rules typically used in aeronautics: optimized non-standard plates are lighter (about 10%) than standard ones with equivalent or superior mechanical properties. The effectiveness of the developed configurations is proven through an a posteriori experimental campaign of buckling tests conducted at I2M laboratory. The experimental results are in excellent agreement with those provided by numerical simulations.

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# Numerical model of DCB test of Fiber Metal Laminate

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Delamination is one of the failure mechanisms which could occur in layered composite materials and hybrid multilayer structures called FML (Fiber Metal Laminate). This phenomenon could occur in each step of exploitation - in manufacturing process or during their operation. Appearing a small cracking between layers and its further spread leads to decreased stiffness and lower or even lost of load capacity of structure. The propagation can follow three fracture schemes modes I, II and III, and also a combination of this modes. However, the most crucial factor during delamination development is the first type of loading (crack opening). Thus this phenomenon should be investigated in details.

Literature is rather poor in the investigation of delamination process in FMLs. Some experimental studies limited only to determining the value of crack parameters could be found. However, similar studies on 'classical' FRP composite materials showed that the distribution of SERR exhibits specific features for off-axis layer orientation.

This paper is devoted to numerical analysis of Double Cantilever Beam test to determine fracture parameter (Strain Energy Release Rate) in FML and its distribution of SERR along the sample width. Performed numerical analysis is referred to ASTM D 5528. Cracking between aluminum layer and prepreg sheet was modeled using CZM and VCCT Method. While previous study confirmed that on fracture parameters influence only adjacent layers, thus in analysis only layer of aluminum sheet and prepreg, where delamination occurs, were modeled. The numerical model of DCB test with $G_1$ distribution for exemplary sample are presented in Figure 1. The influence of fiber orientation in composite layers on delamination process was analyzed as well as delamiation position within entire laminat.

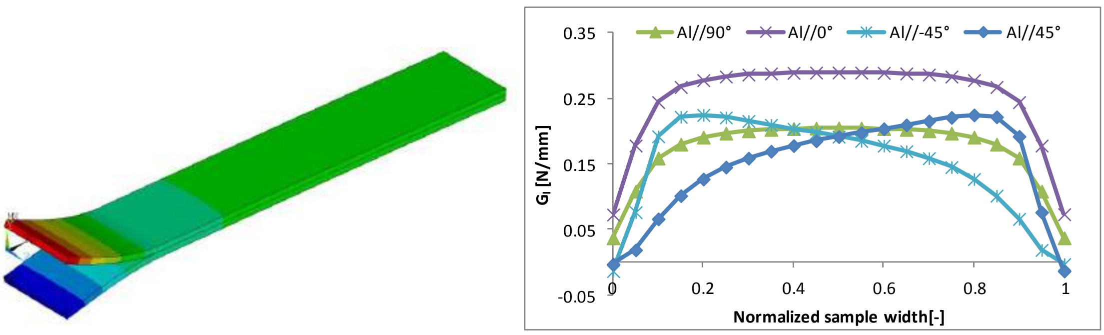


Figure 1 Numerical model of DCB test and distribution of SERR along sample width.

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# STRENGTH OPTIMISATION OF VARIABLE ANGLE TOW LAMINATES

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Variable angle tow (VAT) laminates represent the new frontier of lightweight composite structures. The modern automated fibres placement (AFP) techniques allow considerably increasing the freedom in design. The trajectory of the tows can be properly conceived in order to optimise the properties of the resulting structure and can be adapted to the local distribution of stress and strains (within each ply).
In this work a multi-scale two-level (MS2L) optimisation strategy for optimising the strength of VAT composites is presented. The MS2L strategy aims at determining, at the first level, the optimum distribution of the strength and stiffness properties of the structure (in terms of the polar parameters of the laminate), while at the second level the optimum path (in each constitutive layer) matching locally the polar parameters resulting from the first step. The MS2L strategy relies on the one hand on the use of the polar formalism [1], [2] for the description of the anisotropic behaviour of the composite and on the other hand on the use of a particular genetic algorithm (GA) able to deal with a special class optimisation defined over a domain of variable dimension.
At the first level of the MS2L optimization strategy the goal is the strength optimisation by minimizing an opportune laminate-level failure index formulated and expressed in the framework of the first-order shear deformation theory (FSDT) [3]. Requirements on first buckling load and mass of the multilayer plate are integrated as optimization constraints.
The MS2L approach is firstly applied to a Finite Element (FE) model of the VAT composite. In a second time, a surrogate model of the structure is developed in the framework of the proper generalized decomposition (PGD) and the MS2L methodology is applied in this context in order to find an optimum solution in a reduced time by minimizing the computational effort.

## References

[1] G. Verchery. Les invariants des tenseurs d'ordre 4 du type de l'élasticité. In Proceeding of the Euromech Colloquium 115: 93-104, Villard-de-Lans, France, 1979.
[2] M. Montemurro. An extension of the polar method to the first-order shear deformation theory of laminates. Composite Structures, 127: 328-339, 2015.
[3] A. Catapano, M. Montemurro. On the correlation between stiffness and strength properties of anisotropic laminates. Mechanics of Advanced Materials and Structures. https://doi.org/10.1080/15376494.2017.1410906

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# COMPUTATIONAL HOMOGENISATION FOR THERMO-MECHANICAL PROPERTIES OF CORK-BASED COMPOSITES

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Among industrially useful natural materials the cork is one of the lightest woods, with excellent sound and thermal insulating properties thanks to its honeycomb-like microstructure[1]. If on one hand the lightweight and insulating properties of cork can represent a very important advantage in industrial applications (civil, aeronautic, aerospace, etc.), on the other hand its softness represent a limitation. Therefore, in order to extend the field of application of such an interesting material, cork is often embedded in polymeric matrix in order to obtain a stiffer particle reinforced composite.

Cork composites, as many particulate-reinforced materials, are characterized by multiform particles/grains leading, at the micro-scale level, to complex stress/strain distributions and damage mechanisms. Such a complex behavior depends upon several parameters like: geometry and distribution of the particles, mechanical and chemical interaction at particle/matrix interfaces, etc. Concerning the first aspect, in order to generate a realistic representation of the microstructural geometry and distribution of particles, a proper computational model has been developed. In particular an algorithm, written in Python, able to reproduce the actual microstructure of particulate-reinforced materials, with different volume fractions, degree of heterogeneity and randomness has been developed.

Based on Voronoi Tesselation, it generates the geometry of particles, matrix and voids considering geometric, design and manufacturing variables as parameters.

In a second time, the generated 2D artificial microstructure arranged in a Representative Volume Element (RVE) has been utilized to perform:

- the strain energy-based homogenization of elastic properties;
- the asymptotic expansion homogenization of thermal properties;

of the cork-based composite[2].

Thermo-mechanical properties of an equivalent homogeneous material have been estimated and numerical results have been compared with the experimental ones taken from literature in order to show the effectiveness of the proposed model. Furthermore, the influence of the degree of heterogeneity and randomness, on the effective material properties has been investigated.

[1] Gibson, L.J., Easterling, K.E., Ashby, M.E., 1981. *The structure and mechanics of cork*. Proceedings of the Royal Society of London A377, 99–117.
[2] H. Dumontet, *Homogénéisation et effets de bords dans les matériaux composites*, thèses d'état de l'université Pierre et Marie Curie Paris 6 (1990).

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# COMPUTATIONAL HOMOGENISATION AND MICRO-CRACKING ANALYSIS OF PIEZOELECTRIC CERAMICS

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Piezoelectric ceramics are employed in several applications for their capability to couple mechanical and electrical fields, which can be advantageously exploited for the implementation of smart functionalities. The piezoelectric coupling, which can be exploited for fast accurate micro-positioning devices or other kinds of transducers, makes such materials suitable for applications in micro electro-mechanical systems (MEMS).

However, due to their brittleness, piezo-ceramics can develop damage leading to initiation of micro-cracks, which can affect the performance of micro-devices. For such reasons, the development of accurate and robust numerical tools is an important asset for the design of such systems.

The most popular numerical method for the analysis of micro-mechanical multi-physics problems, still in a continuum mechanics setting, is the Finite Element Method (FEM). Here we propose a novel alternative integral formulation for the grain-scale analysis of degradation and failure in polycrystalline piezo-ceramics. The formulation is developed for 3D aggregates and inter-granular failure is modelled through generalised cohesive laws, which take into account the presence of the electro-mechanic coupling at interface level.

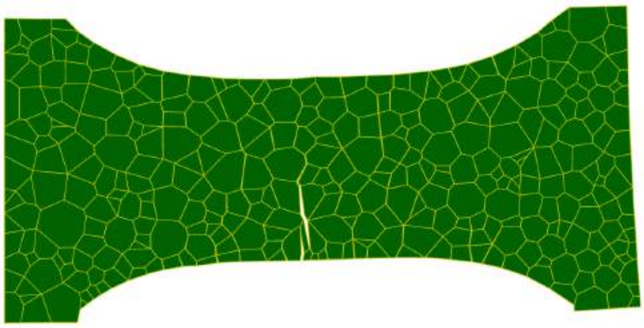

Figure 1: Artificial polycrystalline piezo-electric micro-morphology with simulated crack nucleation.

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# STUDY ON THE SUBSEQUENT YIELDING SURFACE AND CONSTITUTIVE EQUATION OF METALLIC FOAM UNDER MULTI-AXIAL LOADING

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There has been no consideration of multi-axial effect on study of the full multi-axial constitution of metallic foam, and it is because that the subsequent yielding surface of the metallic foam under multi-axial loading is unclear yet. A 3D Voronoi model was built to simulate the metallic foam with meso structures, which is verified experimentally. With such a model, the mechanical behaviors of the metallic foam can be simulated numerically with the properties of the metallic matrix. In order to get the multi-axial responses, abundant numerical simulative experiments were carried out under monotonous multi-axial loading with different triaxial proportions. By analyzing the stress and strain relations of the metallic foam under different triaxial proportional loading, the true normal stresses $\sigma_x$, $\sigma_y$, $\sigma_z$ in three directions and the average stress $\sigma_m$ against the true volume strain$\varepsilon_b$ are investigated by considering effects of the triaxial proportion. Further, by eliminating the parameters of triaxial proportion, the equation of subsequent yield surface against the volume strain can be derived, and the constitutive equations of metallic foam under multiaxial loading may be presented.

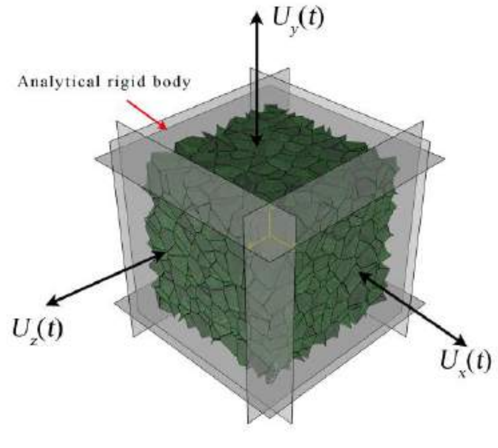


Figure 1 3D Voronoi model under multi-axial loading

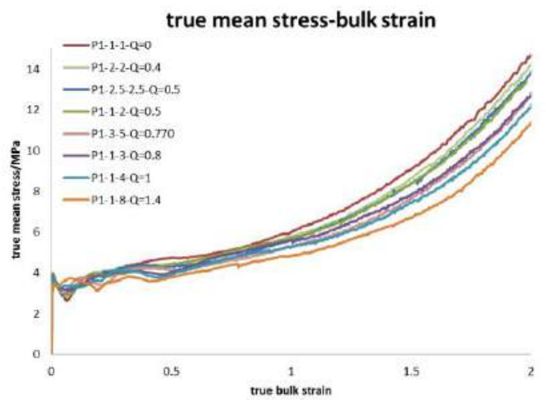


Figure 2 the mean stress-bulk strain relation under multi-axial loading with different triaxial proportion

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# NON UNIFORM RATIONAL B-SPLINES (NURBS) HYPERSURFACES FOR METAMODELING: APPLICATION TO A COMPOSITE STIFFENED PANEL

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Computers increasing performances are widely utilized to improve simulation complexity over computation time. However, some applications need quasi-real-time models mostly for design/optimization purposes. Metamodeling techniques can minimize the computational effort to realize complex simulations (multi-field, multi-scale, etc.). Currently, Artificial Neural Networks (ANN), Proper Generalized Decomposition (PGD), Fuzzy Logic (FL) and Radial Basis Functions (RBFs) are the most common methods available in literature having their own limitations. For example, ANN are often not suitable for multiple outputs request, while PGD provides less accurate results for nonlinear problems. However, all these methods need a great amount of data available (extensive experimental, numerical campaigns, etc).

This study aims at providing an original metamodeling technique based on the Non-Uniform Rational B-Splines (NURBS) formalism. In CAD applications, NURBS are well-known for their ability to fit intricate surfaces. Here the idea is to fit very general sets of data points by extending the NURBS formalism to the N-dimensional hypersurface case. The shape of such NURBS hypersurface is described by several parameters: number of control points (CPs), their coordinates and related weights, degrees of the blending functions and knot-vector components defined along each direction. Few research studies deal with the use of NURBS hypersurfaces as surrogate models and parameters are often set through empirical rules and/or iterative procedures: only CPs number and coordinates are optimized, while other parameters are fixed a priori. In this work, an original genetic algorithm solving problems defined over a variable dimension design space is considered to determine automatically (i.e. without the user's intervention) the optimum number of CPs as well as all the parameters tuning the shape of the NURBS hypersurface at a given approximation precision.

To prove the effectiveness and the robustness of the proposed approach, the method is first applied to a meaningful benchmark and then results on a real world engineering case are presented.

# GLOBAL HYBRID STRATEGY FOR MULTI-SCALE CHARACTERIZATION OF COMPOSITE MATERIAL PROPERTIES WITH NON-DESTRUCTIVE TESTS

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One of the main issues of composite materials is related to the difficulty of characterizing the full set of material properties at both mesoscopic and microscopic scales.
Indeed, classical mechanical tests (traction/compression, 3 and 4 points bending tests, etc.) are not able to provide the full set of 3D material properties of composites. Furthermore, these tests can usually provide only the in-plane elastic properties of the constitutive lamina (i.e. at. the mesoscopic scale). Therefore, to go beyond the main restrictions imposed by standard destructive tests, this work deals with the desire of characterizing the material properties of a composite plate, at each characteristic scale, through a single non-destructive dynamic test performed at the macroscopic scale, i.e. that of the specimen.
To face such a problem a general multi-scale identification strategy (MSIS) is proposed.
The MSIS aims at identifying the constitutive properties at both micro and meso-scales by exploiting the information restrained in the laminate macroscopic dynamical response. In this context it is possible to characterize both elastic and viscoelastic micro-scale properties. The MSIS relies on the one hand on the strain energy homogenization technique of periodic media (to get the effective material properties of the lamina as a function of the geometrical and material properties of the microscopic constitutive phases) and on the other hand on a specific hybrid algorithm (genetic + gradient-based algorithm) to perform the solution search for the problem.
The identification problem is stated as a constrained inverse problem (a least-square constrained problem), where the objective function depends upon both the measured (from experiments) and numerical (from FE analysis) dynamic response of the plate.
In order to validate the effectiveness of the MSIS, the measured dynamic response is obtained, in a first time, by using a numerical test conducted on a *reference structure*, to check the robustness and the reliability of the proposed methodology. The optimization variables are both geometrical and material properties of the constitutive phases composing the representative volume element of the composite.
In the end, the effectiveness of the MSIS is then validated through a campaign of experimental/numerical tests conducted on composite laminates.

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# NUMERICAL SIMULATION OF PENETRATING IMPACT IN A BIOLOGICAL TISSUE SIMULANT USING MESHLESS METHOD.

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Gelatin is commonly used in ballistic testing as a substitute for biological tissue simulant. Experimental characterization of this kind of material is a challenging problem involving costly, and complex experimental setups. Another way to study this complex material is the numerical simulation, whose use is made more difficult, since the framework of the studies involve large deformations, high velocities, and more generally non-linear phenomenon. In order to understand penetrating impacts at a numerical level, an interesting way consists in the use of smoothed particles hydrodynamics (SPH) formulation, which does not involve any mesh of the structure and which allows very large deformation. Thus, the present study proposes to investigate perforating impact in a ballistic gelatin material using this method. Ten configurations of penetrating impacts from the literature have been numerically reproduced. A constitutive model as well as an adequate equation of state were implemented in the model to simulate the complex behavior of the gelatin. Numerical results were compared to experimental data as illustrated in Figure 1. Figure 2 provides pressure distribution.

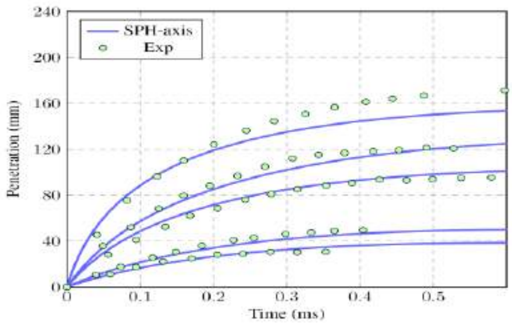


Figure 1: Numerical-experimental data of projectile penetration at different impact velocities

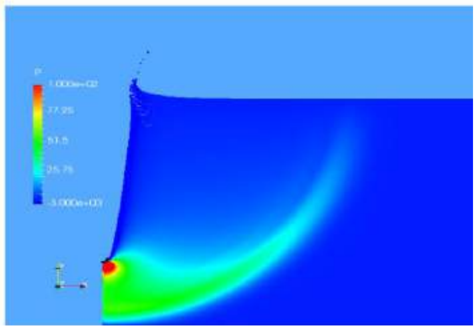

Figure 2: Ballistic impact on %20 ballistic gelatin (Coloration: pressure).

The results obtained at different impact velocities and for different diameters of the projectile, were provided, and were close to the experimental data. Whereas the mechanical behaviour of the this structure is considered in the literature as viscoelastic, hyperelastic, or a hyper-viscoelastic, with strain rate dependency, the constitutive law of the material used in this study was an hydrodynamic-elasto-plastic relation, whose mechanical parameters have been considered in a sensitivity study, to investigate their influence on the results of the ten considered impact cases.

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# IMPLICIT MESH DISCONTINUOUS GALERKIN FOR VARIABLE ANGLE TOW MULTILAYERED PLATES

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This works presents a novel computational scheme for variable angle tow (VAT) multilayered plates [1]. The characteristic features of the proposed scheme are the combined use of a discontinuous Galerkin (dG) formulation and an implicitly defined mesh. The formulation is based on the principle of virtual displacements (PVD) and the Equivalent Single Layer (ESL) assumption for the mechanical behavior of the VAT plates [2].

The problem is first placed within the dG framework by suitably introducing an auxiliary variable and by rewriting the set of equations governing ESL VAT plates as a first-order system of differential equations. Following Arnold et al.[3] and by introducing suitably defined average and jump operators, the primal formulation for ESL theories of VAT multilayered plates is obtained. Two dG formulations are considered, namely the Internal Penalty and the Compact Discontinuous Galerkin methods, which are obtained by suitably specifying the corresponding numerical fluxes.

Subsequently the numerical implementation is discussed. First, the mesh elements are defined using a reference background quad-tree grid and the implicit representation of the considered domain's boundaries. Then, the elemental matrices are computed using the algorithm proposed by Saye [4] for the integration over implicitly defined domains and boundaries. To show the potential of the scheme, numerical tests are performed on VAT plates with simple and more complex geometries such as curved edges and cutouts.

## References

[1] *Oliveri, V., Milazzo, A., "A Rayleigh-Ritz approach for postbuckling analysis of variable angle tow composite stiffened panels," Comput Struct,* **196***, page 263-276 (2018).*

[2] *Carrera, E., Demasi, L., "Classical and advanced multilayered plate elements based upon PVD and RMVT. part 1: Derivation of finite element matrices," Int J Numer Meth in Eng,* **55***, page 191-231 (2002).*

[3] *Arnold, D.N., et al., "Unified analysis of discontinuous Galerkin methods for elliptic problems," SIAM J Numer Anal,* **39***, page 1749-1779 (2002).*

[4] *Saye, R., "Implicit mesh discontinuous Galerkin methods and interfacial gauge methods for high-order accurate interface dynamics, with applications to surface tension dynamics, rigid body fluidstructure interaction, and free surface flow: Part I," J Comput Phys,* **344***, page 647-682 (2017).*

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# CHARACTERIZATION OF MECHANICAL COMPONENTS MANUFACTURED VIA ADDITIVE AND SUBTRACTIVE PROCESS: A COMPARISON OF THE BEHAVIOR UNDER LOW-VELOCITY IMPACTS.

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Additive manufacturing (AM) is more and more used in the framework of mechanical product development allowing producing complex structures which cannot be designed with other process, like subtractive manufacturing (SM). Like for classical process, obtained components need to be mechanically characterized, in order to see if they satisfy the requirements, specifically for strength, and mechanical constraints. However, the number of studies dealing with mechanical characterization is limited.

Figure 1 additive and subtractive mechanical components under impact loading

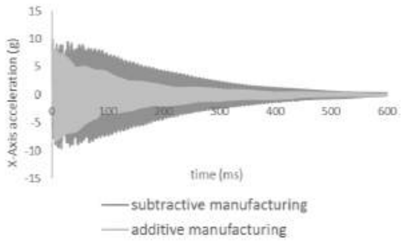


Figure 2 acceleration curves for both structures (AM) and (SM)

Indeed, in order to investigate and characterize the process of AM, a part of a scooter was design using this process, using a 3D printer and the process of selective laser melting (Renishaw AM 250, Renishaw ©) using aluminium powder. The same component was designed via subtractive manufacturing. Both structures were instrumented with accelerometers and were submitted to low velocity impacts using a shock hammer, as illustrated in figure 1. The order of magnitude of the impact forces was 60-100 N in order to ensure to remain in the elastic domain, and to avoid risks of plasticity and rupture. Accelerations curves (figure 2), frequencies, damping effects of vibrations, and also porosities of the structure via CT scans were of particular interest, illustrating the differences between the two process for the design of mechanical structures.

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# STUDY OF THE INFLUENCE OF COUPLING AGENTS OVER THE ADHESION FORCE OF DISSIMILAR OVERMOLDING POLYMERS: A DIGITAL IMAGE CORRELATION ANALYSIS

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The increasing of technical and functional requirements of plastic artifacts has led the development of multi-materials. To achieve a good performance in the adhesion of dissimilar materials: in the present case, polypropylene and coconut fiber composites, is fundamental to understand the phenomena related to the specific interface. This work has the object to evaluate the adhesion force of different multi-materials, more specifically between overmolded polymer-coconut composites using the digital image correlation (DIC) technique. First, coconut fiber composites were prepared using three different coupling agents; next, they were overmolded with polypropylene. The results shown that coupling agents have positive influence, providing increase on the mechanical properties of such multi-materials under tensile stress. The Lagrange vectors obtained by DIC analysis point out higher stress concentration at the joint edges, where the occurrence of surface cracks led the samples to fail in the region close to the overlap, preferably on the side of the composite before the peeling stresses forces happened as shown in Fig. 1.

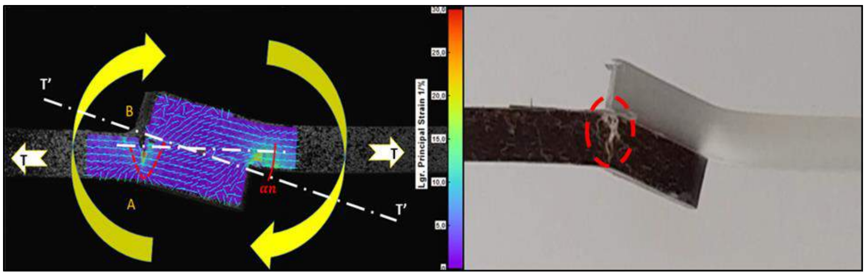

Figure 1. *DIC stress state analysis of the composite*

This study may contribute to the dissemination of the adhesion technology of dissimilar materials, increasing the possibility of using composites with natural fibers in multi-component injection processes.

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# FINITE ELEMENT ANALYSIS FOR THREE-DIMENSIONAL FLOWS OF GENERALIZED NEWTONIAN FLUIDS

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A mixed least-squares finite element model with spectral/*hp* approximations is developed to analyze steady, three-dimensional flows of generalized Newtonian fluids whose viscosity follows the Carreau-Yasuda constitutive model. The finite element model cosisits of velocity, pressure, and stress fields as independent variables (therefore, called a mixed model). Finite element models based on least-squares formulations are considered an alternative variational setting to the conventional weak-form Galerkin models for the Navier--Stokes equations, and no compatibility conditions on the approximation spaces are needed for the field variables if the polynomial order (p) is sufficiently high (say, p>3, as determined numerically). Also, applying high-order spectral/*hp* approximation functions to the least-squares formulation avoids various forms of locking which often occur in low-order least-squares finite element models for incompressible viscous fluids, and accurate results can be obtained with exponential convergence. The problem of flow in a lid-driven cavity is solved to verify the model. Then a parametric study is performed to examine the effect of change in parameters of the Carreau-Yasuda model on the flow behavior.

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# A THERMOMECHANICAL THEORY FOR HYPERELASTIC SEMI-LINEAR MATERIAL

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This study presents thermo-mechanical theory for a thermally-sensitive hyperelastic semi-linear John's material. A generalized temperature-dependent energy function is developed for the solid and the resulting thermal stress which measures the temperature-dependent mechanical response in the hyper-elastic solid is obtained via the Frechet derivative of the generalized energy function with respect to the gradient of deformation. Furthermore, the first law of thermodynamics, Fourier's law of heat conduction, and the obtained thermal stress are employed to formulate coupled equation of motion and generalized heat conduction equation governing temperature-deformation interactions in the solid. It is observed that the thermoelastic problem under consideration is realized when, in addition to the temperature field, the hyperelastic body is acted on by rapidly varying external loads, which may give rise to a rather significant redistribution of the temperature field in the body, and this in turn may entail a redistribution of stress field. Finally and in the special case of hyperelastic slab with internal energy generation and variable thermal conductivity, the temperature, deformation and stress distributions are obtained.

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# $P_D$SO application for FE based design of a damping system for smart composite structure

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In the last two decades, the use of piezoelectric materials has growing up due to their inherent capability to react to external stimuli or input and to sense any modification to either their own state or modification of host structure, see Gaudenzi (2009). These intrinsic characteristics have opened effective applications of these materials in the framework of structural health monitoring (Duan et al., 2010; Mancini et al., 2006; Zou et al., 2014), active and passive vibration control (Hagood and von Flotow, 1991; Vasques and Rodrigues, 2006), as well as energy harvesting (Priya et al., 2009).

In the framework of vibration control, the reduction of structural vibration can be achieved by both active (Gaudenzi et al., 2000; Jiang et al., 2000; Lam and Ng, 1999) and passive control (Lesieutre, 1998; Thomas et al., 2012). In particular, the passive vibration damping represents a simpler and cheaper technique when compared with the active control, since the latter involves a damping system layout with at least two piezoelectric devices, one as a sensor and one as actuator, to be bonded on the host structure while the passive scheme requires the piezoelectric device to be shunted to a suitable external electrical circuit.

On the afore-mentioned basis, a finite element design approach for a damping system to be applied in layered smart beams is presented in this paper. Finite Element model, developed by Alaimo et al. 2015, implements the first-order shear deformation beam theory and is based on the preliminary analytical condensation of the electric state to the mechanical state. This allows to establish an effective mechanical beam kinematically equivalent to the original smart beam including the effects of electro-elastic couplings. The contributions of the external electric loads are included in both the equivalent stiffness properties and the equivalent mechanical boundary conditions. Hermite shape functions, which depend on parameters representative of the staking sequence through the equivalent electro-elastic stiffness coefficients, are used to formulate the finite element method. The state space representation is then invoked for the assembled smart beam finite element model to favour its implementation in a block diagram environment for multi-domain simulation. In order to optimize the damping performance, the Population Decline Swarm Optimization ($P_D$SO) procedure (Orlando and Alaimo 2017) is introduced and used to select the optimal parameters for the damping system. The $P_D$SO procedure is based on a decline demographic model and shows high global search capability with reduced computational costs.

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# Enhanced Beam-Theory Derived Shear Stress Distributions in Tramway Rails

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In many urban areas, tramways are the backbone of the local public transport system imposing high requirements on its reliability. During service, rail fractures and material degradation due to wear or environmental influences are the main causes of disruptions. Rail fractures occur if the loads acting onto the rails induce stress states which exceed the strength of the steels the rails are made of. In the case of rail transport, these loads, resulting predominantly from the rail car axles, are not only extraordinary high, but also concentrated on small contact areas between the rail car wheels and the rails.

In this study, the fracture tendency of tramway rails is investigated by employing a novel shear-compliant beam theory, considering normal and shear forces, bending moments as well as primary and secondary torsional moments.

Our main interest lies in shear stress distributions throughout the cross sections of grooved rails. Interestingly, the locations of maximum shear stresses arising from discontinuities in shear forces, as encountered with abrupt changes in the embedment conditions, agree remarkably well with fracture patterns observed in real life. This marks a new level of advanced computational mechanics entering railway engineering.

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# Numerical simulation of the multiaxial fatigue behavior of titanium lattice structures

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Additive manufacturing (AM) allows fabricating lattices (i.e., cellular structures with a periodic arrangement of cells along either two or three dimensions) by aggregation of materials in a layer-by-layer fashion.
The mechanical properties of Ti6Al4V periodic structures with different unit cell designs (rhombic dodecahedra, octet, cubic, hexahedron, etc.) have already been studied in literature. However, the fatigue behavior of these structures is not yet well understood.
Usually, most of the methods for fatigue design rely on experiments but they are time consuming and expensive. Therefore, the development of a computational methodology able to predict the fatigue behavior of lattice structures considering a realistic stress distribution is a topic of paramount importance that has not yet been fully addressed.
This work aims at proposing a numerical model able to predict the mechanical response of the lattice (at each pertinent scale) under multiaxial cyclic loads. The model is properly parametrized (in terms of both mesh and geometry) to take into account different configurations of the lattice.
Numerical results show that the lattice fatigue strength depends upon both the relative density and the geometrical features of the unit cell.
Finally, an experimental campaign of multiaxial fatigue tests has been conducted on some selected lattice configurations to characterize the fatigue behavior of these periodic structures and to catch the basic mechanisms concerning crack initiation and propagation to stress localization within the microstructure.

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# A nonlocal higher-order curved beam model for bending, stability, free and force vibrations

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In the present work, bending, stability, free and force vibrations analysis of curved nanobeams is investigated using the differential constitutive law, consequent to Eringen's strain-driven integral model, coupled with a higher-order shear deformation. The formulation developed here is general in the sense that it can be deduced to examine the influence of different structural theories: Euler-Bernoulli, Timoshenko and higher-order model such as Sin. Furthermore, the influence of the behaviour law and the classical hypothesis of beam, $\sigma_{33} = 0$ is outlined as the present model could have stretching effect capability. The governing equations derived are solved in conjunction with Naviers solutions and employing finite element method by introducing a 3-nodes curved beam element. The formulation is validated considering problems for which solutions are available. A comparative study is made using various structural models. The effects of various structural and material parameters such as thickness ratio, beam length, rise of the curved beam, boundary conditions, and size-dependent or nonlocal parameter are brought out on bending, stability and vibration behaviours of curved nanobeams.

## References

[1] M. Ganapathi, O. Polit, Dynamic characteristics of curved nanobeams using nonlocal higher-order curved beam theory, *Physica E: Low-dimensional Systems and Nanostructures* 91 (2017) 190-202.

[2] T. Merzouki, M. Ganapathi, O. Polit, Vibration study of curved nanobeams based on nonlocal higher-order shear deformation theory using finite element approach, *Composite Structures* 184 (2018) 821-838.

[3] T. Merzouki, M. Ganapathi, O. Polit, A nonlocal higher-order curved beam finite model including thickness stretching effect for bending analysis of curved nanobeams, *Mechanics of Advanced Materials and Structures*, to appear.

[4] M. Ganapathi, O. Polit, A nonlocal higher-order model including thickness stretching effect for bending and buckling of curved nanobeams, *Applied Mathematical Modelling*, to appear.

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# ELECTRO-CHEMO-MECHANICAL MODEL FOR POLYMER ELECTROLYTE MEMBRANES

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Polymer electrolyte membranes, such as Nafion, are thin films which are employed in micro-batteries and proton-exchange-membrane fuel cells. These devices are expected to play a significant role in the next generation energy systems for use in vehicles as a replacement to combustion engines. During operating conditions, large changes in humidity and temperature may occur inducing swelling and shrinking of the membrane. Therefore, a premature failure can take place determining short life and degradation of performances. It is usually complicated to investigate the behavior of thin films through experiments due to the smallness of these devices. Numerical simulations are carried out in order to enable a better understanding of the phenomena and of the multi-physics couplings occurring in these micro-scale polymeric materials.

In the present research, a thin Nafion membrane is investigated by using a three-dimensional continuum-based electro-chemo-mechanical (ECM) model. The solvent-ions-polymer mixture is viewed as a single homogenized continuum body. Different physics are modeled: (i) water uptake/release, (ii) ion transport, (iii) nonlinear mechanics and (iv) electrostatics. The multi-field formulation presented in this work utilizes the balance equations of the electro-chemo-mechanical field theory and admissible constitutive processes which are consistent with the thermodynamic principles (dissipation inequality). In the mechanical field, a multiplicative decomposition of the deformation gradient is employed: (i) a distortional part, related to the ion motion, and (ii) an elastic part, related to the water diffusion. The multi-field model is numerically solved within the finite element framework. Time-dependent simulations are performed by using the commercial tool COMSOL Multiphysics.

Concluding, the developed ECM model allows to investigate the space and time evolution of the main electro-chemo-mechanical variables under different working conditions. Then, we aim at updating the ECM model by introducing an elastic and inelastic damage effect: the first takes into account for possible cracks of the material due to hydration-dehydration cycles, whereas the second takes into account for aging effects.

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# FLEXURAL FAILURE ANALYSIS OF COMPOSITE STRUCTURAL INSULATED PANELS WITH MGO BOARD FACINGS

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Sandwich panels are readily used in civil engineering due to their high strength to weight ratio and the ease and speed of assembly. A Composite Structural Insulated Panel (CSIP) in consideration consists of magnesium oxide (MgO) board facings and expanded polystyrene core and is characterized by immunity to biological corrosion, a high thermal insulation and a low impact on environment. Due to a complex nature of layered structures any modification of panel's geometry leads to difficult-to-foresee changes in their performance, which are identified in a series of costly full-scale laboratory tests. A nonlinear numerical model was created, with a use of a commercial ABAQUS software and a user-defined procedure, which is able to reproduce observed failure mechanisms. FEA parameters were established on the basis of small-scale tests and numerical experiments. The model was validated by a comparison with the results of full-scale tests.

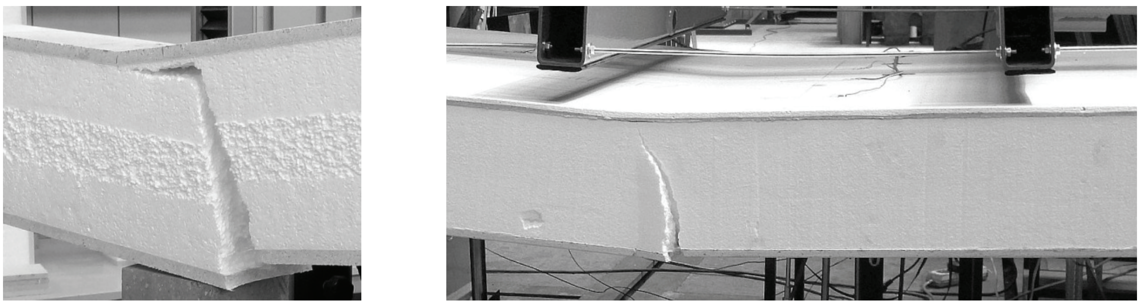

Figure 1 CSIP flexural failure in a small-scale sample (left) and a full-scale panel (right).

The scope of the current research is aimed at prediction of MgO board facing failure in flexure (Fig. 1). Numerical simulations of 7 small-scale tests on samples of different geometries were used to perform parameter identification of the FEM model and full-scale panel bending test data was utilized for verification. An attempt at obtaining a single criterion for facing failure in flexure proved to be problematic; samples of different geometry reached the level of failure load at a significantly different level of the equivalent plastic strain. Moreover, an artificial local reinforcement of 1 mm thin band of facing material was introduced in the contact zone with the core. Both the issue of reinforced band and failure initiation criteria in flexure are the subject of current analysis.

# TESTING THE FREQUENCY RANGE OF TIMOSHENKO BEAM THEORY

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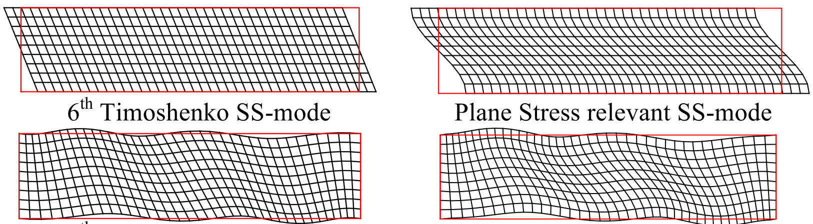
The theories describing the dynamic behavior of freely vibrating beams and plates could be contained in four main categories as: (i) classical theory, (ii) first order shear deformable theory (FSDT), (iii) higher order shear deformable theories (HSDT) and (iv) three-dimensional theory (3D). Being the beam however the structural element over which the leading modelling idea has originated. In particular, the classical beam theory (*i.e.* Euler-Bernoulli beam theory) is appreciated by engineers for its own simplicity. However, this theory sometime does not suffice and needs of a step forward which is identified in the use of Timoshenko's theory (1921, *Philosophical Magazine*, xli, 288-290).

The Timoshenko beam theory has been recently discussed further by Stephen and Puchegger (2006, *Journal of Sound and Vibration*, 297, 1082-1087) with regard to a frequency range within which the same theory should be used. These authors by accepting their investigation could be limited in its scope encouraged other researchers to conduct similar investigation so that a definitive view on the validity range of Timoshenko beam theory could be agreed.

Based on the fact that the Timoshenko's theory even today represents a good compromise between complexity of the model and reliability of simulated frequencies, within this presentation an in-depth investigation is carried out in order to further analyze the validity range of Timoshenko beam theory. The investigation is performed by comparing the results provided by Timoshenko model with those obtained by a plane stress (2D) model. Several boundary conditions are analyzed and compared; whenever possible the systems of partial differential equations are exactly solved (*i.e.,* all cases of boundary conditions for Timoshenko model and the simply supported case of (2D) plane stress model) whilst, alternatively, approximate analytical methods solve all the cases where an exact solution is unfeasible. The approaches used to solve the equations do not discuss the possible existence of a first and/or a second spectrum of natural frequencies; the system of partial differential equations of Timoshenko model is integrated by recurring to a stationary approach through the method of exponential matrix. Therefore, the extracted frequencies achieved as solutions are assumed to belong to a unique spectrum and accompanied by mode shapes whose analysis is conducted to reasonably identify a limit frequency representing an upper bound for the solution of Timoshenko model.



6th Timoshenko SS-mode — Plane Stress relevant SS-mode

8th Timoshenko CC-mode — Plane Stress relevant CC-mode

Figure 1 Mode shapes (S: simply supported, C: clamped)

# SUBLAMINATE VARIABLE-KINEMATIC MODELS FOR VIBROACOUSTIC ANALYSIS OF COMPOSITE TRIM PANELS

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In recent years, cabin noise quality and speech intelligibility has become increasingly important in the aerospace industry. Various solutions have been studying with the aim of improving the interior acoustic comfort, especially for VIP aircrafts and helicopters. One effective approach is to adopt inner fuselage panels, called trim panels, specifically designed for optimizing the acoustic absorption or the transmission loss (TL). Trim panels have typically a classical sandwich multilayer structure featuring a fundamental pattern of two stiff and thin outer sheets called skins enclosing a relatively thick low-density core. The materials and thickness of core and skins, the number of layers of external sheets, the topology of the core and the total and relative thickness are, among others, important design parameters affecting the acoustic performances of the panel. The acoustic design can be further complicated by the adoption of less-conventional and innovative configurations involving multiple cores.

Even if only an experimental test can certify the achievement of desired performances, simulations can be carried out on suitable mathematical models to guide the design process, i.e., to evaluate the effect of the main parameters and to study the nature and arrangement of layers. However, accurate modeling of multilayered trim panels for vibroacoustic analysis is challenging, mostly due to their highly heterogeneous anisotropic constitution in the thickness direction and the wide frequency range of interest. In particular, it can be difficult to identify sufficiently simple yet reliable theoretical models without unnecessary complexity.

In this work, a powerful and effective numerical tool for the acoustic analysis of finite-size composite trim panels having classical and complex advanced sandwich configurations is presented. Main feature of the proposed formulation is the versatile kinematic representation of the displacement field along the thickness direction, consisting in the representation of the plate by means of sublaminates, i.e. arbitrary groups of plies composing the panel. Each sublaminate is associated with an independent and arbitrary kinematic description, either equivalent single-layer or layerwise, so that the use of refined high-order theories can be tailored to specific thickness subregions. The way of writing the equilibrium equations allows the hierarchical generation of multiple models of the plate from the same unified framework. Some vibration and TL results on different trim panels are reported and discussed to show the effectiveness of the proposed approach by comparing the numerical predictions with experimental data.

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# A VISCOPLASTICITY MODEL FOR METALS WITH TWO-TEMPERATURE THERMODYNAMICS

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We develop a physics-based model for dislocation mediated thermoviscoplastic deformation of metals in a two-temperature framework. There have been significant progresses over several decades in the understanding of underlying physics and developing predictive models for thermoviscoplastic deformation in the metallic structures. For instance, the Johnson-Cook model, which is one such popular empirical model, has been widely used. In many of these models, phenomenological material characterization includes parameters that are not only devoid of physical meaning but also occasionally hard to determine from experiments. Consequently, attempts have been made in arriving at physics/mechanism-based constitutive models for viscoplasticity (e.g.-Zerilli and Armstrong) that assign clearer physical meaning to the terms and parameters introduced in the material characterization.

With a view to developing a physics based thermoviscoplastic model of metals, the thermodynamic system should include state variables capable of describing defect motion, lattice distortion as well as thermal vibration. The plastic deformation involves two processes: the fast kinetic vibration of atoms about their equilibrium positions in the lattice and atomic rearrangements associated with the irreversible movement of dislocations, i.e. configurational degrees of freedom. These two processes occur in widely separated time scales and allows us to identify two weakly interacting subsystems: the configurational subsystem of slower degrees-of-freedom and the kinetic-vibrational subsystem of faster degrees-of-freedom. These two subsystems have their own entropies and energies and hence their own temperatures as well. As the plastic deformation sets in and continues because of external driving, the two temperatures evolve differently and establish a heat current from the configurational subsystem to the other. A large fraction of the external work that generates dislocations and keeps them in motion thus dissipates as heat. This provides the dissipative character of viscoplastic deformation in the two-temperature thermodynamic framework and also suggests the configurational rearrangements to be far from equilibrium.

We have taken the dislocation densities (e.g. mobile, forest dislocation) as internal variables to develop the model. The predictive quality of the model is verified through a series of numerical simulations under uniaxial deformation conditions as well as 3D cases (Taylor Impact Test). However our present research is applicable only to body-centered cubic (BCC) and face-centered cubic (FCC) metals.

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# STOCHASTIC TIME DOMAIN SPECTRAL ELEMENT FORMULATION OF SANDWICH BEAMS

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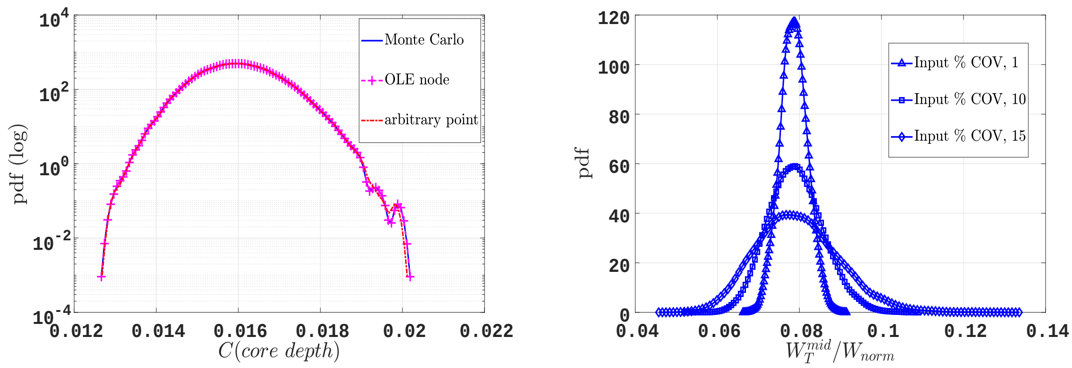
Sandwich structures have received great attention in various engineering fields like naval, automobile, aerospace etc. due to high specific strength and stiffness. The sandwich panel suffers from uncertain material and geometric properties arising from the manufacturing process. In this work, a stochastic time domain spectral element method (STSEM) is proposed for sandwich beam structures considering higher order sandwich panel theory. The core thickness is considered as 1-D non-Gaussian random field and optimal linear estimation (OLE) is used for the discretization of the same. Computationally efficient time domain spectral element method (TSEM) is used to develop the STSEM formulation.

Figure 1 (a) shows the log probability density function (pdf) of the log-normal distributed field obtained at OLE nodal points and any arbitrary points and also compared with the random field obtained from Monte Carlo simulation. Figure 1 (b) Shows the pdf of the normalized mid-point displacement of a simply supported beam subjected to sinusoidal distributed load considering different input variability on the core depth. In this work, the response statistics of the simply supported beam for static and free vibration problems are investigated and the computational efficiency of the proposed method is discussed in detail.




(a) (b)

Figure 1: (a) Log pdf of generated random field at OLE nodes and arbitrary point, (b) pdf of mid-point displacement of a simply supported beam subjected to sinusoidal distributed load

# CHARACTERIZATION OF THE ADHESIVE BONDING BETWEEN HYPERELASTIC MATERIAL AND SURFACE TREATED FIBERS

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Due to the versatile material morphology and the resulting unique material properties elastomeric materials are predestinated for the application as damping material but also an interesting alternative for classical resin based composite systems in load coupling applications. A combination of soft elastomers with stiff fibers enable the built up of a composite with very strong direction dependent properties. The adhesion between fiber and matrix material are strongly influenced by the fiber surface functionalization. However, to characterize these interactions several different test methods like the fiber pull-out test can be used. In this work, a novel test setup was implemented to perform fiber bundle pull-out tests, which enable the possibility to investigate the combination of stiff fibers with a hyperelastic matrix material. This combination leads to several issues for the test implementation, due to the introduced load on the fiber matrix interface by clamping the specimen. Therefore, a specially designed sample holder was manufactured, to ensure both, (1) the accurate alignment of the specimen in the test setup and (2) the implementation of the experiment without a compressive clamping of the hyperelastic matrix material.

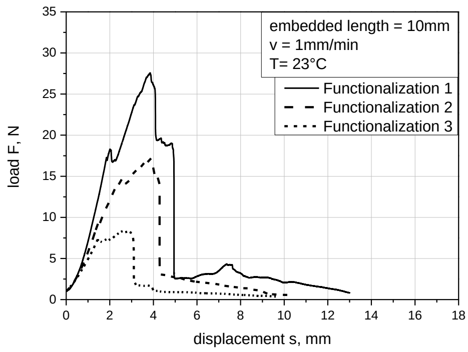


Figure 1 Load depending on the displacement for different surface treated fibers.

Furthermore, an experimental design was developed and implemented to verify the test setup for different fiber functionalizations. Additionally, the pull-out speed and the embedded length were varied to characterize their impact on the adhesive bonding behavior. As depicted in figure 1, the different surface functionalization reveal a clear different load displacement behavior. The results show a strong dependency of each varied parameter on the adhesive bonding strength of the fibers in the hyperelastic material.

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# A REDUCED MODEL FOR HANDLING THE INSTABILITIES OF LONG FIBER REINFORCED COMPOSITE WITH MULTILEVEL FINITE ELEMENT METHOD

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The fiber microbuckling in long fiber composites may lead to the compressive failure of the macrostructure. To study such a multiscale problem, direct simulation is limited due to the expensive computation cost and difficulties in selecting non-linear calculation paths because there exists a lot of bifurcation points around the useful one. This work is to propose an efficient multiscale model for accurately simulating and analyzing the instability phenomena of long fiber reinforced materials. The multilevel finite element method ($FE^2$) is adopted to realize the real-time interaction between macro- and microscopic levels: the macroscopic constitutive law is calculated on the Representative Volume Element (RVE), and the microscopic deformation gradient is transferred from the associated macroscopic Gauss point. However, the total computation cost may be still every high because the RVE on each Gauss point of macroscopic model needs a sufficient fine mesh to simulate the microbuckling of long fibers. Thus, a Fourier related double scale microscopic model is developed to transform the fast varying microscopic unknowns into a series of slowly varying unknowns which only requires remarkably reduced meshes. In addition, the new RVE model allows one to control non-linear calculation paths easily by choosing the wavelength of the buckled fiber, for example, Figure 1 gives a specific instability pattern with two half waves. The developed non-linear multiscale model is solved by the Asymptotic Numerical Method (ANM), which is less time consuming and more stable than other classical iterative methods. The established multiscale model yields accurate results with a significantly improved computational efficiency, see Figure 2.

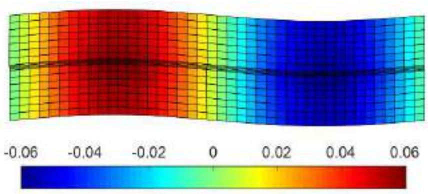


Figure 1 The fiber microbuckling subjected to compressive load.

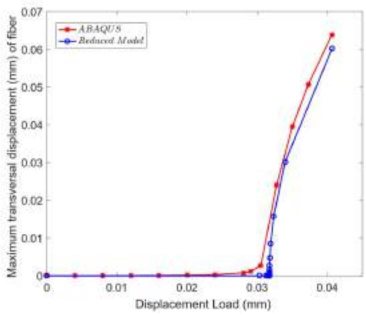


Figure 2 The bifurcation curves for fiber microbuckling.

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# NEWTON'S SERIES EXPANSION BASED THEORIES IN THE FRAMEWORK OF CARRERA'S UNIFIED FORMULATION FOR THE ANALYSIS OF PLATES

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In this talk, the well known Carrera's Unified Formulation (CUF) [1] is extended by formulating some new families of theories by means of Newton's series expansion. This latter represents a compact manner to define a polynomial approximation such that Taylor, Lagrange, Hermite and generalised Hermite polynomial bases can be all derived from it.

Thanks to CUF, a generic theory is derived by means of a variational statement in terms of representative nuclei that do not depend upon the through-the-thickness approximation type nor the order. The resulting boundary value problem is solved by a Navier closed form analytical solution.

Results are compared with solutions available in the literature or developed via a commercial finite element code and they show the accuracy and versatility of the used approach.

## References

[1] E. Carrera. Theories and finite elements for multilayered plates and shells: a unified compact formulation with numerical assessment and benchmarking. *Archives of Computational Methods in Engineering*, 10(3):216–296, 2003.

# Artificial Microstructure Generation for Representative Volume Elements of Fiber Reinforced Composites

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While fiber reinforced composites such as glass and carbon fiber composites have the potential for equivalent properties as metals at a lighter weight, variations in the microstructure can lead to high variability and even early failure. For unidirectional lamina, this variability can, in part, be attributed to the variation in the fiber/matrix microstructure. Current microstructural modelling practices now include random placement/packing of fibers, but Representative Volume Elements (RVEs) are still likely to be two dimensional, assuming the fibers to be perfectly aligned and the microstructure to be prismatic. While this is a sufficient first step, the assumption of axially aligned fibers fails to consider on of the main drivers of a variable microstructure, which is the slight entanglement of fibers. This work reports on ongoing research to artificially generate fiber bundle microstructures using processing-inspired modelling, and to compare the characteristics of artificial fiber entanglement with actual fiber packings quantified through micro-imaging. Using appropriate statistical descriptors, artificial RVEs can be assured to contain the same features as real composites, and eventually fine-tune the prediction of property scatter for composite materials.

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# RELATIVE STUDY ON SANDWICH STRUCTURES REINFORCED IN THICKNESS: NUMERICAL APPROACH

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Sandwich structures are increasingly used in various industrial sectors. The combination of different components provides complementary properties. This leads to obtaining a structure capable to meet very demanding specifications.

Traditionally, 2D sandwich structures are made by stiff thin skins and lightweight thick core. Sandwich materials have good mechanical properties especially under flexion loading. But, their performances are limited mainly to transverse shear loading. Hence, introducing reinforcement in the thickness is an appropriate solution to improve its mechanical properties mainly under transverse shear loading. In this case we are talking about 3 D sandwich structures or sandwich materials reinforced in thickness.

In this work homogenization by finite element method analysis is used to evaluate the equivalent mechanical properties of reinforced foam in the thickness. Fiberglass reinforcement introduced at ± 45 ° is considered (Figure 1). A parametric study is performed according to different parameters. The parameters concerned are the rate of reinforcements in the foam, the volume fraction of the fibers in the reinforcements, the shape of the reinforcements and the distribution of the reinforcements in the foam.

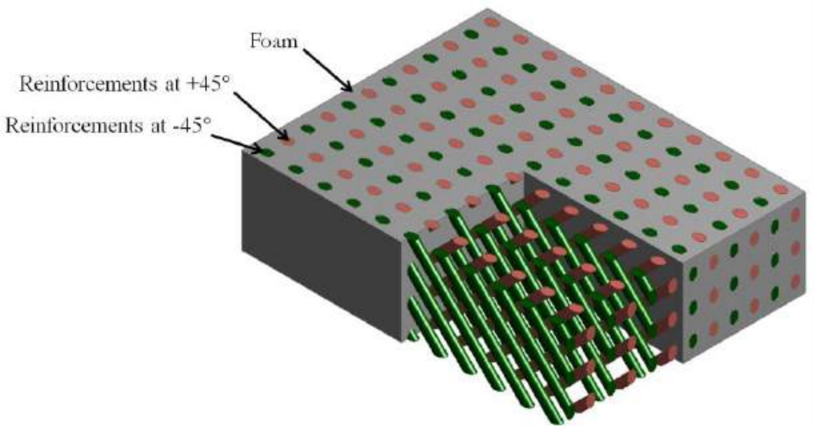


*Figure 1: Representation of foam reinforced in the thickness by reinforcements made of fibrous composites at ± 45°.*

This study shows the interest of reinforcing sandwich structures in the thickness. All the results show that the improvement of the mechanical properties is significant, especially the properties in shear and normal in the out-of-plane direction.

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# BENDING OF PIEZO-ELECTRIC FUNCTIONALLY GRADED PLATES

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Structural elements such as beams, plates, shells are often used as components in micro- and nano-electromechanical systems (MEMS and NEMS). In particular, two types of piezoelectric materials widely used in smart structure applications are piezo-ceramics and piezo-polymers. Due to polarization methods (used to initiate the piezoelectric properties), the piezo-ceramics often adopt the mm6 crystal structure whereas the piezo-polymers are of the mm2 crystal structure. The former is a degenerate subset of the latter crystal structure. Thus the choice of mm2 structure is general enough to cover the piezoelectric materials often associated with smart structures. The original 3D electro-mechanical boundary value problem can be converted into 2D problems by adopting certain assumptions for plate structures and performing integration with respect to the transversal coordinate (averaging over the thickness). In this paper, we develop a unified formulation for plate bending problems with incorporating the assumptions used in three plate bending theories, such as the classical Kirchhoff-Love theory for bending of thin plates (KLT), as well as the 1st and 3rd order shear deformation plate theory (FSDPT and TSDPT). Two key factors are used for switching among these three theories. Both the governing equations and boundary conditions are derived from the variational formulation with allowing the material coefficients to be functionally graded. The functional gradations bring coupling effects between the bending and in-plane deformation modes. The transversal gradation of material coefficients does not basically increase the mathematical complexity of the problem. On the other hand, it is significantly increased in case of in-plane gradation of material coefficients and/or variable thickness of the plate because the governing equations become the PDE with variable coefficients. Therefore we pay great attention to development of advanced numerical technique for solution of these multi-field problems via mathematical simplifications with preserving the physical nature of phenomena. Numerical simulations will be used for illustration of the response of piezoelectric plates to external influences.

## Acknowledgements

The financial support by APVV-14-0440 (Slovak Research and Development Agency) is greatly acknowledged.

# SNAP-BACK MECHANISMS OF RODS SUBJECT TO KINEMATIC BOUNDARY CONDITIONS

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The quasi-static behavior of Euler's planar rod kinematically constrained at the two ends is investigated through the elastica, the analytical solution expressed by means of Jacobi elliptic functions. With reference to an inextensible Kirchhoff's rod with uniform bending stiffness, the possible non-unique equilibrium configurations are disclosed at varying the three primary kinematical parameters (rotations at the two ends and their relative distance). The stability of the equilibrium configurations is analyzed solving the Sturm-Liouville problem which governs the eigenfunctions to be used as basis for the perturbation field.

The obtained critical conditions define the set of configurations for which a snap-back mechanism occur and can be represented as surfaces within the three dimensional space having the three primary kinematical parameters as axes. The theoretical predictions of the present model are confirmed by numerical simulations performed through the commercial code Abaqus, and are in a good agreement with the results from experimental tests developed under symmetric conditions obtained by Plaut and Virgin [1] and Beharic et al. [2].

References:

[1] Plaut R. H., Virgin L. N. (2009). Vibration and Snap-Through of Bent Elastica Strips Subjected to End Rotations, Journal of Applied Mechanics 76 / 041011-1

[2] Beharic J., Lucas T. M., Harnett C. K. (2014). Analysis of a Compressed Bistable Buckled Beam on a Flexible Support, Journal of Applied Mechanics 81 / 081011-5

Acknowledgments:
The authors gratefully acknowledge financial support from the grant ERC advanced grant `Instabilities and nonlocal multiscale modelling of materials' ERC-2013-AdG-340561-INSTABILITIES (2014-2019).

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# RIGOROUS AMENDMENT OF VLASOV's THEORY FOR THIN ELASTIC PLATES ON ELASTIC WINKLER FOUNDATIONS

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Deflection modes relevant for plates with rigidly supported edges are commonly used as kind of "approximation" for plates which are freely swimming on an elastic foundation. However, this approach entails systematic errors at the boundaries. As a remedy to this problem, we here rigorously derive a theory for elastically supported thin plates for arbitrary boundary conditions, based on the principle of virtual power. Somewhat surprisingly, it appears that the well-known Laplace-type differential equation for the deflections needs to extended by additional boundary integrals entailing moments and shear forces, so as to actually "release" the boundaries from "spuriously" acting external moments and shear forces. The principle of virtual power also provides a natural access to an algebraic system of equations providing a real, approximation of the solution for the deflections in the format of a double trigonometric series, converging to the true solution with an increasing number of series members. The new method is applied to relevant problems in pavement engineering (see Fig. 1), and it is validated through comparison of respective numerical results to numerical predictions obtained from Finite Element analysis.

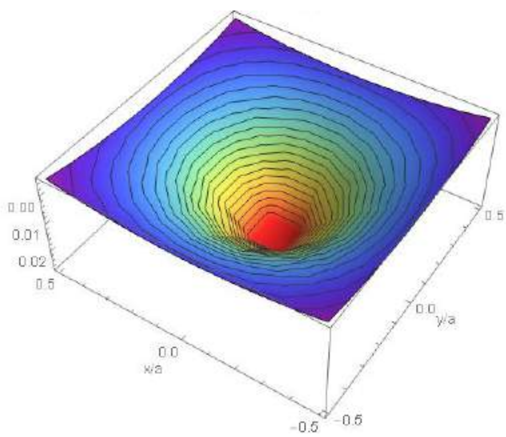


Figure 1: Dimensionless deflections $\left[(wEh^3)/(a^2P)\right]$ according to the principle of virtual power, for a quadratic plate with edge length $a$, thickness $h$, elastic modulus $E$, and Winkler modulus $c$; stemming from a vertical point force $P$ acting in the plate's center

# Strain-rate modelling of composite materials by a fractional derivative approach

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This paper is focused on modelling of compositeś behavior under dynamic loading. The strain-rate effect can be observed in some orthotropic directions due to the viscoelastic properties of polymer matrix. In order to model this phenomenon, a Zener model with fractional derivatives is developed for a single ply of composite laminate in shear direction. The fractional derivative approach is a good technique to model the viscoelastic behaviour for some heterogenic materials such as composite materials with a polymer matrix. The developed fractional model allows to represent envelopes of the loading curves for different strain-rates using the data of a quasi-static test. Fractional model involves a few parameters which are easily identified through an optimisation procedure from the experimental data. The detailed optimisation procedure and physical meaning of model parameters are considered in this paper. The model is validated for thermoset and thermoplastic composite materials at different strain rates. The benefit of this approach is a simple numerical implementation and a low computational cost. The simple numerical modelling may significantly simplify the material characterisation at different strain-rates and improve the material pre-conditioning.

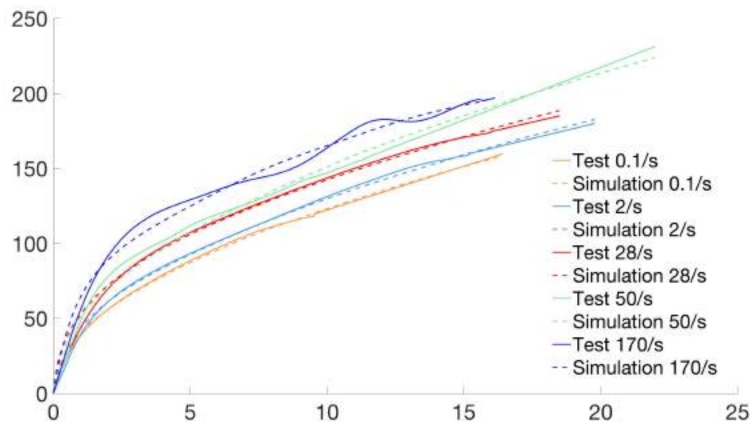


Figure 1: Simulation of the strain rate effect for thermoplastic composite.

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# VARIABILITY OF MECHANICAL PROPERTIES OF VISCOELASTIC SANDWICH STRUCTURES DETERMINED BY AN INVERSE IDENTIFICATION METHOD

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In this study, we focus on symmetric three layered viscoelastic sandwich. The core viscoelastic material properties (shear modulus $G_0$ and loss factor $\eta_C$) is identified on modal analysis on sandwich beam. However, variations can be observed in experimental results (Figure 1). Our aim is to quantify the variability due to experimental characterizations and take into account in numerical model.

Thus, experimental vibration tests are performed to determine resonant frequencies and loss factors for different bending modes of a symmetric three layered viscoelastic sandwich beam. We propose to study the variability and the robustness based on these different parameters: useful lengths, number of specimens and temperature.

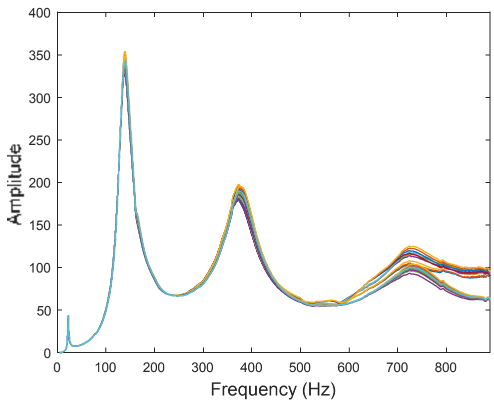


Figure 1 Amplitudes of displacement of a clamped-free beam as a function of the frequency at 30°C

The obtained results will be compared with the literature, particularly those of K. Sepahvand and S. Marburg, who develop [1,2] a robust and efficient inverse stochastic method based on the non-sampling generalized polynomial chaos method for identifying uncertain elastic parameters from experimental modal data.

[1] K. Sepahvand, S. Marburg, "On construction of uncertain material parameter using generalized polynomial chaos expansion from experimental data", IUTAM Symposium on Multiscale Problems in Stochastic Mechanics (2013) 4–17.

[2] K. Sepahvand, S. Marburg, "Identification of composite uncertain material parameters from experimental modal data", Probabilistic Engineering Mechanics 37 (2014) 148–153.

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# MODAL ANALYSIS OF ROTATING VISCOELASTIC ASYMMETRIC SANDWICH BEAMS

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In industrial fields, rotating structures such as, wind turbines, propellers and turbines can undergo significant vibrations up to resonance inducing annoying noises and damaging structures. Therefore, the precise determination of the natural frequencies of these structures is an important step in their design. In applications where the use of light structures is important, the introduction of a viscoelastic material between two elastic layers is widely used to induce a high damping inherent to the resulting multilayer structure. The rigidity of this type of structure depends on the frequency of vibration. According to our knowledge, no prior work has taken into account this dependence between stiffness and frequency in rotating sandwich beams. However, these materials have been widely studied in the case of non-rotating beams. Bilasse et al[1], for example, solved the complex nonlinear eigenvalue problems of symmetric viscoelastic non-rotating sandwich beams with a frequency-dependent Young's modulus, by coupling the homotopy technique and the asymptotic numerical method (HANM).

In our study, we use the HANM procedure to determine the dynamic parameters of rotating asymmetric viscoelastic sandwich beams with a constant uniform cross section. Our results obtained for viscoelastic sandwich rotating beams with a constant Young's modulus coincide perfectly with those obtained from literature and the software Abaqus. The originality of our work is the consideration of the dependence of Young's modulus on frequency in the study of asymmetric rotating sandwich beams. To this end, we studied the effect of angular velocity and layer thicknesses on eigenfrequencies and loss factors. Results show that, similarly to the isotropic beams, the sandwich ones gain in rigidity as the angular velocity rises inducing the increase of the eigenfrequencies and the decrease of the loss factors. Other important results observed is the fact that the dimensionless fundamental frequency does not change with damping coefficient, regardless of the angular velocity. In addition, when the angular velocity increases, the loss factor converges to the same value, regardless of the damping coefficient. From the variation of layers thicknesses, it has been noticed that the symmetrical sandwich beam is the most suitable for damping vibrations.

[1] M. Bilasse et al. A generic approach for the solution of nonlinear residual equations. Part II: Homotopy and complex nonlinear eigenvalue method. Computer Methods in Applied Mechanics and Engineering 198 (2009) 3999-4004

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# INVESTIGATION OF MECHANICAL PROPERTIES ON 3D-PRINTED STRUCTURED BEAMS TO INCREASE VIBRATION ABSORPTION

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With additive manufacturing, complex structures can be realized to increase mechanical properties in many materials. Here, structured composite beams are designed by extrusion 3D printing based on fused deposition modeling technologies in polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS).

This study presents an investigation of the mechanical properties especially the dynamic response as function of different parameters. The influence of the shape, the period and the amplitude of the corrugations are already improved on metallic sheets [1]. Thanks to additive manufacturing, the authors explore unusual periodicity of the shape to propose some configurations for which resonance frequencies can be shifted.

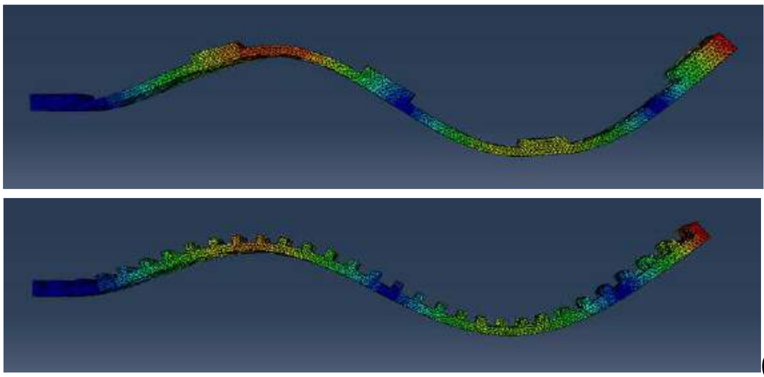
(a)
(b)

Figure 1: 3rd frequency resonance modal analysis of two different structured beams clamped-free.

Two investigations are proposed: a numerical model with corrugation shape form CAO and experimental analysis. Tensile test is used to determine mechanical properties for the PLA material such as tensile strength and modulus. Modal analysis is used to identify the dynamic behavior of the 3D composite beams. From the obtained results, this study demonstrates that within an appropriate shape the resonance frequencies can be shifted.

[1] G. Robin, N. Mathieu, M. Jrad, E.M. Daya, F. Choquart, "The effect of the geometric parameters of the corrugation shape on the vibration analysis of 3D structured beams", Mechanics Research Communications (84), 2017, Pages 65-71, ISSN 0093-6413.

# An approach for modelling the damping of flax-epoxy laminated composite

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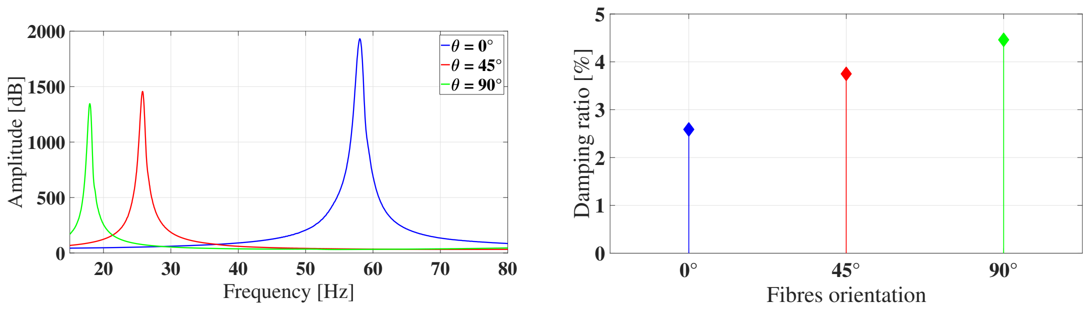
The aim of this study is to compute the eigenvalues and damping of natural composites. Herein a modelling of the damped vibration behavior of flax-epoxy laminated composites is proposed. The mechanical properties of each layer are identified experimentally via tensile tests. The dynamic characteristics (damped eigenfrequencies and modal damping ratios $(\eta_k)$) are derived from the vibration tests (Fig.1).




(a) (b)

Figure 1: Effect of the fiber's orientation on the fundamental eigenfrequency (a), and its corresponding modal damping ratio (b).

For numerical investigation, the damping ratio is considered constant and it is introduced in Youngs modulus in the following form : $E_k = E_0(1+i\eta_k)$. The homogenization technique is applied in order to obtain the behavior law of the structure. Then, to investigate the damped vibration problem of these composite structures, the discretization method is applied where a finite isoparametric shell element with eight nodes is used. The resolution of the equation of vibration is carried out using the Asymptotic Numerical Method (ANM). This method associates a high order perturbation method and a homotopy technique. The initial complex problem is linearized and a set of linear algebraic system is able to be easier solved. The damping $(\eta)$ and damped frequency $(\Omega)$ of the structure are defined from the classical formula of : $\omega^2 = \Omega^2(1+i\eta)$.

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# STOCHASTIC STRENGTH PREDICTION OF BRAIDED COMPOSITES: MULTISCALE DAMAGE MODELING AND UNCERTAINTY QUANTIFICATION

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Braided composites combine high structural stability with low cost, exceptional damage tolerance and attractive energy absorption due to yarn interlacing. The rapid growth of braided applications requires well developed failure predictions, which can accurately calculate material behaviors and specifically the initiation and propagation of damage. However, failure and strength analysis is more demanding than stiffness prediction, since nonlinearities in material models and contact assumptions have to be introduced, along with failure criteria and material degradation models. Uncertainty assessment approaches have not been applied to strength predictions yet, as there are no studies established on a probabilistic framework.

This study attempts a multiscale modeling framework, accounting for a variety of uncertainties, under static tensile loading states. A numerical microscale model was established for the strength properties prediction of the yarns, under different loading conditions. 3D Hashin and modified von Mises (Christensen) failure criteria were applied to the mesoscale model, along with a stiffness degradation scheme in a user-defined subroutine for ABAQUS. A variety of random parameters are introduced to the system, covering a wide range of material and geometrical uncertainties, caused by either lack of knowledge or manufacturing processes. The response variability of the macroscale strength properties is calculated within a Monte Carlo framework.

Some numerical aspects are also discussed, since all algorithms must be kept robust and computationally effortless, due to the probabilistic nature of the models. When it comes to the variability influence and sensitivity of random parameters, efficient surrogate modeling techniques are proposed, in order to overcome the computational burden of the FE discretization and the curse of dimensionality. The study is expected to provide a first insight towards stochastic analysis in terms of strength prediction for braided composites, but also highlights the importance of realistic uncertainty quantification.

# Geometrically non-linear hierarchical finite elements for the analysis of bi-stable beam structures

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In the framework of novel computationally efficient solution approaches for the design of multi-stable engineering applications (such as actuators, morphing structures, deployable structures, energy harvesters and MEMS), this work presents the formulation of a family of advanced one-dimensional finite elements for the geometrically non-linear analysis of mechanically bi-stable beam mechanisms. The approximation order of the kinematic field along the beam thickness is a free parameter of the analysis and it is a-priori assumed via Carrera's Unified Formulation (CUF). In the framework of a total Lagrangian approach, the principle of virtual displacements is used in order to obtain the tangent stiffness matrix of the element. A Mixed Interpolation of Tensorial Components (MITC) has been adopted in order to tackle the shear and membrane locking phenomena and improve the convergence performance of the proposed elements.

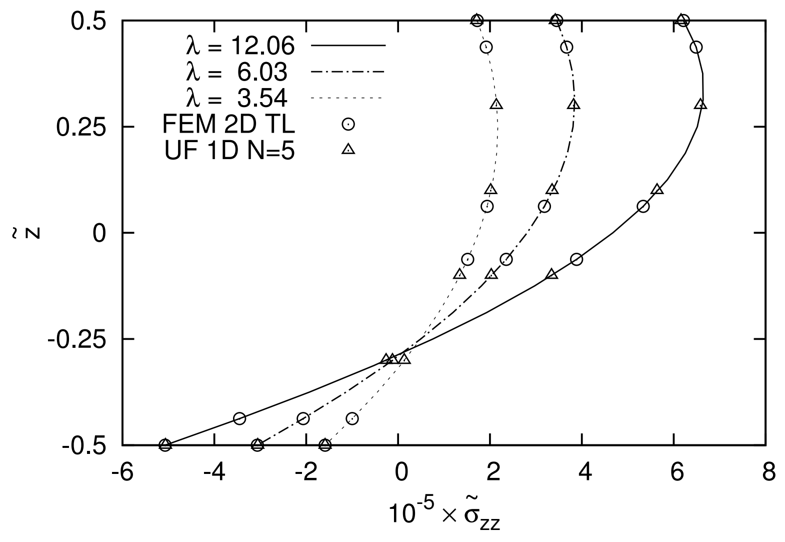


Figure 1: Accurate prediction of the through-the thickness stress $\tilde{\sigma}_{zz}$ via one-dimensional CUF-based finite elements for different load factors $\lambda$. Simply supported beam.

The proposed modelling approach is demonstrated to lead to an accurate prediction of the snap-through path as well as a full stress state evolution in bi-stable beam structures with reduced computational costs compared to commercial software finite elements.

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# Hierarchical Beam Finite Elements for Multi-scale Geometrically Nonlinear Analysis of Beam Structures via Multi-scale Asymptotic Numerical Method

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The aim of this paper is to develop a computationally efficient multi-scale framework by coupling Carrera's Unified Formulation [1], [2] (CUF) to a multi-scale asymptotic numerical method [3] (Multiscale-ANM) to simulate and analyze the instability phenomena of composite beam structures. At macroscopic level, several higher-order refined beam elements can be easily implemented via CUF by deriving a fundamental nucleus that does not depend upon the approximation order nor the number of nodes per element (they are free parameters of the formulation). Multiscale-ANM combined finite element square method with Asymptotic Numerical Method [4] (ANM). The unknown macroscopic constitutive law is obtained by the Representative Volume Element on the microscopic level, and the microscopic deformation gradient is calculated from the macroscopic model. Compared to other iterative classical methods, ANM is more reliable and less time consuming. Results are validated in terms of accuracy and computational costs towards FEM solutions. Numerical investigations show that accurate results can be obtained with reduced computational costs.

# References

[1] E. Carrera. Theories and finite elements for multilayered plates and shells: a unified compact formulation with numerical assessment and benchmarking. archives of computational methods in engineering. *Archives of Computational Methods in Engineering*, 10(3):215–296, 2003.

[2] E. Carrera, G. Giunta, and M. Petrolo. *Beam Structures: Classical and Advanced Theories*. Wiley-Blackwell, 2011.

[3] S. Nezamabadi, J Yvonnet, H. Zahrouni, and M. Potier-Ferry. A multilevel computational strategy for handling microscopic and macroscopic instabilities. *Computer Methods in Applied Mechanics and Engineering*, 198:2099–2110, 2009.

[4] B. Cochelin, N. Damil, and M. Potier-Ferry. Asymptotic-numerical methods and pad approximants for nonlinear elastic structures. *International Journal for Numerical Methods in Engineering*, 37:1187–1213, 1994.

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# Effect of random spatial stiffness variations on the post-buckling behavior of layered structures

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Aerospace structures are optimized to maximize performance of a structure while at the same time minimizing the weight. Expanding the load carrying capability of fuselage panels into the post-buckling region allows more possibilities in optimization. The post-buckling response can be affected by spatial variations of material parameters. These variations can be due to misalignment of fibers, variations in the curing process or other variations in the production process, e.g. [1]. To use panels in the post-buckling regime it is necessary to develop a thorough understanding of how realistic variations can affect the post-buckling mechanical response. The work presented here focuses on the variations in Young's modulus.

Analyzing the post-buckling effect of spatial variations using traditional non-linear methods can be time consuming. To make the analysis more numerically efficient use is made of a reduced order method developed from the work Koiter pioneered and was later expanded on [2]. This method makes it possible to make an approximation of the post-buckling behavior of a structure using a series of linear equations.

Stiffness variations of the structure are implemented through 2D random fields. These fields are generated using a squared exponential autocorrelation function. The method used decomposes an autocorrelation matrix to quickly calculate random fields using discretized points, such as nodes. The advantage to this approach is that the matrix only has to be decomposed once, and the random vectors can be sampled efficiently using LHS type methods, which sample more efficiently.

Two panel-type configurations are discussed in this work. The first consists of three isotropic layers. These are analyzed with a single random field and independent random fields for every layer. The center layer is a low stiffness foam with outer layers made out of aluminium. The second consists of multiple thinner isotropic layers on the faces of the panel. This gives an idea of how stiffness variations can compensate for each other or increase the spread of output parameters such as buckling load and mode shape.

# References

[1] Kepple, J. et al. (2015) Stochastic analysis of imperfection sensitive unstiffened composite cylinders using realistic imperfection models *Composite Structures*, **126**

[2] T. Rahman, S. Ijsselmuiden, M. Abdalla, and E. Jansen (2011) Postbuckling Analysis of Variable Stiffness Composite Plates Using a Finite Element-Based Perturbation Method *International Journal of Structural Stability and Dynamics*, **11-04**

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# MULTIPLE CRACKS LOCALIZATION FOR THIN COATING FILM LAYERS IN PURE BENDING

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Recently, accurate small scale four-point bending flexural tests, for superalloy specimens with multiple ceramic type external coating film layers, have shown that under high loading, the failure mechanism is characterized by the development of complex multiple surface cracks, followed by interior interlayers debonding mechanisms. The final stage is then the complete debonding of the fragmented thermal coating, which leave the interior superalloy completely uncoated. The mechanical problem has an high technological relevance, since failure, or just severe damage, of the ceramic coating, can jeopardize the functionality of structural elements working at high temperature and under severe loadings, such as blades of gas turbines of aircraft engines or high performance electricity generators. This paper presents a nonlinear finite element analysis of the thermomechanical problem modelled as a 2D structure subjected to pure bending. The structural element is composed by an elastic substrate with several thin layers of quasibrittle coating materials, disposed as films in the tensile side of the element. The layers are modelled by an elastic damage constitutive relation and, in order to describe the interlayer decohesion effects, along the layer boundaries and between the first coating layer and the elastic substrate, zero-thickness cohesive-frictional interface elements are disposed.

The presented nonlinear finite element analysis results show the evolution of the fracture patterns and the different possibilities of cracks distribution. It is also analyzed the effects of the thickness of the coating films and the qualitative and quantitative response as function of the fracture energy of the interface compared to the fracture energy in mode I of the coating film. Finally a critical review of the nonlinear response and a general comment on the most efficient strategy for improving the mechanical resistance to failure will be discussed.

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# ROBUST CUF-BASED MIXED AND HYBRID PLATE ELEMENTS

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This paper presents new four- and eight-node quadrilateral finite elements for composite plates. Variable kinematics plate models are formulated within Carrera's Unified Formulation, which encompasses ESL and LW models, with variables defined by polynomials of order $N \in \{1,4\}$ along the thickness direction. Mixed and hybrid element formulations are proposed based on RMVT: the nodal degrees of freedom of mixed elements are transverse stresses and displacements, whereas in the hybrid approach an equivalent displacement-based element is constructed by statically condensing out the transverse stress unknowns. Dedicated interpolation schemes, referred to as QC4 and CL8, are proposed for the transverse shear stress and/or shear strain fields [1, 2]. First results are discussed with particular focus on the shear locking pathology and on the element robustness with respect to mesh distortion.

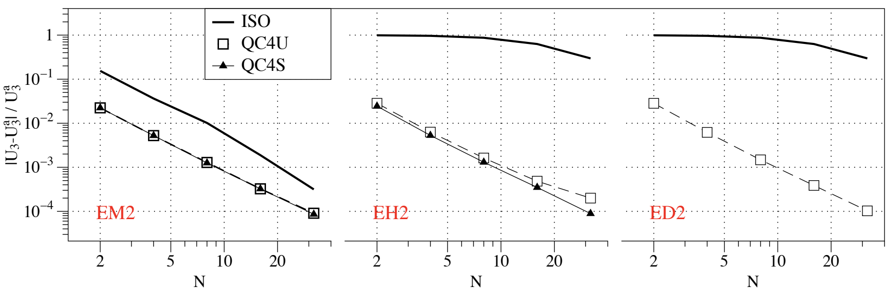


Figure 1: Simply-supported thin (S=100) isotropic square plate, uniform pressure load: convergence of Mixed, Hybrid and Displacement-based 4-node FE with $N = 2$ and isoparametric or QC4 interpolations for displacements or transverse stress fields.

# References

[1] T. H. C. Le, M. D'Ottavio, P. Vidal, and O. Polit. A new robust quadrilateral four-node variable kinematics plate element for composite structures. *Finite Elem. Anal. Des.*, 133:10–24, 2017.

[2] T. H. C. Le, M. D'Ottavio, P. Vidal, and O. Polit. Robust displacement and mixed CUF-based four-node and eight-node quadrilateral plate elements. In H. Altenbach, E. Carrera and G. Kulikov, editors, *Analysis and Modelling of Advanced Structures and Smart Systems*, pages 89–118. Springer Singapore, 2018.

# Resolution of unsteady heat conduction problem with arbitrary heat source location

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Fatigue of materials is a widely studied field. It is one of the main cause of the rupture of structures. It is important to quantify the associated damage phenomenon especially for composite structures. One way consists in studying the heat sources creating by this degradation to understand the involved mechanisms. Thus, the identification of the heat sources can induce numerous problems to be solved. A dedicated computational tool is justified.

Over the past years, the Proper Generalized Decomposition (PGD) has shown interesting features in the reduction model framework, in particular in the context of separation of coordinate variables in multi-dimensional PDEs. The present approach aims at building the explicit solution with respect to the heat source location avoiding the computational cost of numerous computations for different locations. The principle of the method consists in using separated representation of the unknown fields to build an approximate solution of the partial differential equations. We propose to find the explicit solution of the unsteady 1D heat diffusion equation according to the position of the heat source. The solution is written as a sum of products of a time function, a 1D space function and a function varying with the position of the heat source. Hence, we show the influence of the introduction of a new variable (position of the heat source) on the behavior of the method. Despite the simplicity of the problem, some difficulties appear. We present different strategies to improve the performance of this approach Fig.(1). The capability and the accuracy of the method are illustrated through different numerical tests compared with analytical solutions.

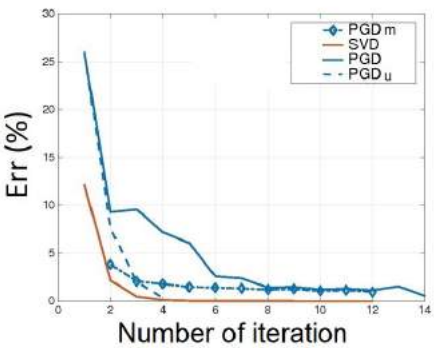


Figure 1: Convergence of PGD for several computational strategies

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# CHALLENGES OF *hp*-ADAPTIVE FEM FOR COUPLED PROBLEMS OF PIEZOELECTRICITY

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In this paper we address the problem of application of the *hp*-adaptive finite element methods originally intended for the uncoupled, or should we say pure, problems of linear elasticity and linear dielectricity to the coupled problems of piezoelectricity. The *hp* methods under consideration are based on the hierarchical 3D-based models of elasticity and dielectricity which combined allow generating a hierarchy of the 3D-based piezoelectric models. The methods take advantage of the hierarchical approximations, constrained approximations and transition approximations which allow $p$- and $q$-adaptivity, $h$-adaptivity and model adaptivity as well, with $p$ and $q$ standing for the element longitudinal and transverse approximation orders and $h$ being the element size. The error estimation which drives the local (element) $p$- and $q$-enrichments, $h$-refinements and the model adaptation is based on the equilibrated residual methods, applied to the approximation and total errors' assessment. These two errors control the discretization adaptivity. The modelling error is defined as a difference of the previous two errors and serves the model adaptivity. In the presented approach the adaption is performed in three steps. In the first one, the solution of the problem is obtained from the initial mesh. Then the error estimation is performed. The obtained error estimates are utilized for the $h$- and model adaptivities. This way the intermediate mesh is formed. After obtainment of the error estimates for this mesh, the $p$- and $q$-adaptivities are performed, which leads to the final mesh. The error estimation completes this third step. The three-step procedure can be repeated iteratively if the target admissible error is not achieved in one iteration cycle.

The main challenges in application of the presented technique, successful in adaptive solution of the uncoupled problems of elasticity and dielectricity, to the coupled problems of piezoelectricity are as follows. Firstly, the discretization of the coupled fields of displacements and electric potential should be performed independently as both fields are characterized with the different discretization errors. This in turn, leads to the necessity of application of different approximation orders or mesh density in both fields, if one wants to perform the discretization with the minimum number of degrees of freedom. The second challenge results from the fact that the residual methods are originally intended for the pure elliptic problems. This means that application of these methods to the coupled problems of piezoelectricity has to be made with care. The same refers to the three-step adaptive algorithms. Here the problem is that the general *hp*-convergence theory, available for the uncoupled problems, does not exist for the coupled problems of piezoelectricity. In consequence, the discretization parameters of the new mesh can hardly be related to the estimated values of the modelling, approximation and total errors. As a result, the optimal mesh may not be generated.

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# HIGH SPEED IMPACT DAMAGE PREDICTION USING THE SMART MATERIALS

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The leading edges of fixed wing aircraft structures are generally made either of composite or metallic materials, which are prone to impact loadings, like bird strike, debris etc. Impact loading is basically transient in nature and it may to lead to severe structural damage. Now a days, there are two new design philosophies are seriously being pursued, in addition to classical approaches, namely a) structural health monitoring, b) damage tolerant. In the present study, the focus is laid on the prediction of impact damage and its propagation with the impact scenarios. The major emphasis is given to interface the smart material towards monitoring the structural behavior and also predicting the residual structural strength after the impact event with the advanced simulation technique mathematical model to address the transient dynamic impact problem.

Shape Memory Polymers (SMP) are the class of smart materials with high strain capability and it has the ability to return to original shape from the set deformed shape. SMP has increased its applicability due to its multi-functionality and reliability with its behavior. SMP can be made as composite patches or layers in the leading edges of wing or horizontal/vertical stabilizers, so that it is able to absorb the high impact strains, besides providing the load carrying capability to the structural component. Numerical model will be made to show the improvement in energy absorption using SMP, for which, a typical aircraft component is used.

Genetic algorithm (GA) is one of the industry accepted search method with proven optimization technique. GA has been successfully applied for many complex problems in all the segments. Here, we adopt effectively GA to arrive at the optimal solution with patch dimensions of the SMP or layers along with the composite laminate, using modal strain energy data. With the patches/layer, transient analysis will be carried out to see the response behavior with and without SMP, to envisage a new energy absorption concept for impact events and eventually monitoring the event by tiny piezoelectric patches in network format.

# Finite Element Model Updating for Identification of Constitutive Parameters in Strain Gradient Theory

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In this research, constitutive parameters for strain gradient theory are identified from full-field measurements by using Finite Element Model Updating (FEMU). First derivatives of strains and so-called length scale parameters are introduced into the constitutive equations of strain gradient theory to demonstrate some phenomena such as size effects and deformation of microstructures which cannot be explained by classical elasticity. It is necessary to experimentally measure the exact value of elastic moduli and length scale parameters for the practical application of the strain gradient elasticity. Identification methods using full-field measurements such as FEMU, virtual fields method, and equilibrium gap method have been developed according to the recent advances in optical devices and image processing. It is possible to identify more accurate and realistic material properties by using such methods especially when the stresses and strains are not uniform. Furthermore, identification methods based on full-field measurement can extract the parameters from a relatively small number of experiments even though the material has heterogeneous or nonlinear constitutive properties. FEMU minimizes the gap between measured and numerical quantities by least-square methods, so it requires a feasible and robust numerical analysis model. For the numerical analysis, finite element method with staggered gradient elasticity based on Ru-Aifantis theorem is used since it only need $C^0$-continuous interpolation functions. Finite element analysis of the strain gradient theory basically requires $C^1$-continuity due to the higher order terms, but staggered gradient elasticity divides the solution process into two step so that $C^0$ elements suffice. The results of the proposed method are verified in a couple of numerical examples.

**Keywords:** Finite element model updating, Full-field measurement, Strain gradient theory

## References

[1] H. Askes, I. Morata, E.C. Aifantis, Finite element analysis with staggered gradient elasticity, Computers and Structures, 2008, Vol. 86, pp. 1266-1279

[2] S. Avril et al., Overview of identification methods of mechanical parameters based on full-field measurements, 2008, Exp. Mech., Vol. 48, pp. 381-402

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# THERMO-MECHANICAL BUCKLING OF SANDWICH STRUCTURES WITH FRP FACES AND FGM CORE

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Generally a functionally graded material (FGM) is a material in which the properties vary continuously with position. In most cases, investigators consider particulate composites for which the volume fraction of the dispersed phase varies continuously through the thickness. In this article, we consider structures in which the properties of the FGM core vary through the thickness in the form proposed by Qian et al. [1]:

$$p(z)=(p_t-p_b)V(z)+p_b$$

where $p$ denotes a generic material property like modulus, thermal coefficients, $p_t$ and $p_b$ denote the corresponding properties of the top and bottom faces of the plate, respectively, and $V(z)$ is a function.

The aim of the present paper is to present a consistent 2D formulation of sandwiches (CS – classical sandwiches and FGMs) that is accurate enough for a prediction of thermo-mechanical buckling load. Various kinematical hypothesis and variational formulations are studied in order to compare them with 3D finite element modeling and to estimate the effectiveness of 2D approximations – see Muc et al. [2,3]. The examples deals with the compressed rectangular plates and shallow cylindrical panels. The effects of boundary conditions on both values of thermal and mechanical buckling loads as well on the variations of bifurcation loads with fibre orientations are discussed in details.

In general, the results show that functionally graded sandwich structures for which material properties of the core vary continuously through the thickness and behave like homogeneous structures.

[1] Qian L.F. et al. Compos: Part B 2004;35:685–97.
[2] Muc A. et al. Appl. Comp. Mater. 2018 (to be published)
[3] Muc A. et al. *Comp. Struct.* 2000;**48**:145-50.

# EVALUATION OF THERMO-MECHANICAL PROPERTIES FOR CNT/EPOXY NANO-COMPOSITES

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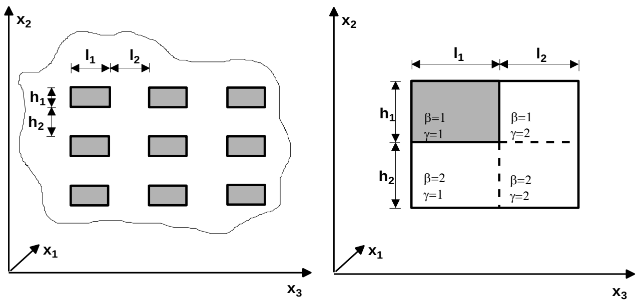
For the thermo-mechanical deformations of nano-composite structures the constitutive relation is given by:

$$\sigma_{ij} = C_{ijkl}\left[\varepsilon_{kl} - \alpha_{kl}\Delta T\right], i,j,k,l = 1,...5$$

σ is the stress tensor, ε is the strain tensor, C is the elastic stiffness matrix, α denotes coefficients of thermal expansion and ΔT is the temperature deviation.

In the present work we focused on the numerical and analytical description of the carbon nanotube-based polymeric nanocomposites to find the complete thermo-elastic behavior of the proposed material model. The work is the extension of our previous studies [1]. For the whole specimen having a periodic distribution of carbon nanotubes, a representative subregion (RVE) can be selected and analyzed to predict the effective material properties – Fig.1.




(a) (b)

Figure 1 Model of continuously reinforced CNT composite: (a) a composite with a doubly periodic array of nanotubes extending in the $x_1$-direction, (b) RVE with four subcells

The transversely isotropic material with aligned and uniformly distributed long carbon nanotubes is considered. For the transversely isotropic nano-composite, the five elastic material constants are needed define the elastic behavior (the stiffness C) and three coefficients of thermal expansions α. The computed material constants for nano-composites are discussed and compared with the data available in the literature as well as with the theoretical model proposed by Aboudi et al. [2] for micro-composites.

[1] Chwał M., Muc A., Compos. B 88 (2016) 295-300.
[2] Aboudi, J. et al., Micromechanics of Composite Materials, Elsevier, 2013.

# Thermal post-buckling of laminated composite structures with temperature dependent properties

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Composite structures such are widely used in various engineering applications such as airplane wings, helicopter blades as well as many others in aerospace, mechanical, and civil industries. These structures are often subjected to elevated temperatures. In such circumstances, high thermally induced compressive stresses will be developed in the structures and consequently will lead to buckling. Since they retain considerable post-buckling strength beyond the thermal buckling load, it is quite advantageous to make use of the post-buckling characteristics in practical design. A number of useful elastic beams, plates and shells theories have been proposed for analysis of thermal post-buckling of composite structures, [1,2] in which the elastic and thermal properties are considered to be independent of temperature.

However, elastic and thermal properties are known to vary with the change of temperature. The temperature-dependent material effect lowered the critical buckling temperatures and increased the post-buckling deflections. The investigation of thermal post-buckling of laminated composites, considering material degradation using finite element methods, and the static buckling of composite plates under thermal loads using layer wise plate theories are presented in [3,4].

In the present work, the thermal buckling and post-buckling analysis of laminated composite beams and plates with temperature dependent material properties is presented. The motion equations are derived applying the asymptotic numerical [5]. A power law distribution in terms of temperature is used and the structure is subjected to a uniform temperature change. The effects of temperature dependent properties, structure geometry and boundary conditions on the thermal buckling and post-buckling behaviours are evaluated through parametric studies. A mathematical formulation that may account for various temperature dependent models is elaborated. Power series expansions of the displacement and the temperature are developed and the finite element method is used for numerical solution.

## References

[1] Singh, G., Venkateswara Rao, G., Iyengar, N.G.R., Thermal post buckling behavior of rectangular antisymmetric cross-ply composite plates, ActaMechanica (1993), 98, 39-50.

[2] Singha, M.K., Ramachandra, L.S., Bandyopadhyay, J.N., Vibration behavior of thermally stressed composite skew plate, Journal of Sound and Vibration (2006), 296, 1093–1102.

[3] L.W. Chen and L.Y. Chen, Thermal post buckling behaviors of laminated composite plates with temperature-dependent properties, Composite Structures 19 (1991), 267-283.

[4] M. Shariyat, Thermal buckling analysis of rectangular composite plates with temperature-dependent properties based on a layerwise theory, Thin-Walled Structure 45 (2007), 439–52.

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# ASYMPTOTIC ANALYSIS OF RING-STIFFENED CYLINDRICAL SHELLS BUCKLING

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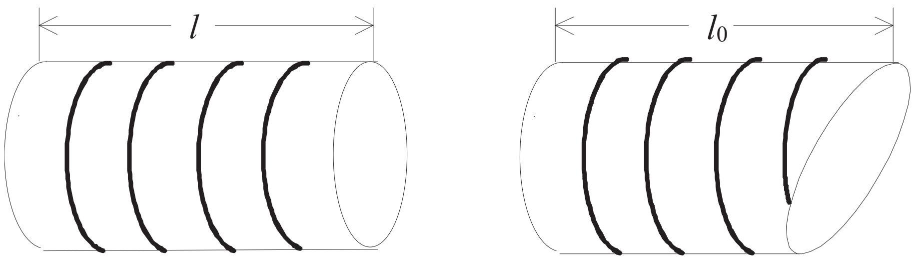
The buckling of thin ring-stiffened cylindrical shells (Fig. 1) under uniform internal pressure is considered. The problem is reduced to the solving eigenvalue problems for systems of linear differential equations. These equations contain the dimensionless shell thickness as a small parameter and therefore lend themselves to be solved by asymptotic approach. Since the boundary conditions for ring-stiffened shells depend on additional small parameters, we use a combination of asymptotic methods to obtain simple approximate formulas for the critical pressure.




*a* *b*

Fig. 1. Ring-stiffened cylindrical shell.

First we seek solutions as a sum of slowly varying functions and edge effect integrals. Thus the initial singularly perturbed system of differential equations is reduced to an approximate system of the smaller order. If the rings may be considered as circular beams the solution of the approximate eigenvalue problem can be obtained by means of homogenization. The wide rings must be considered as annular plates. In this case the initial eigenvalue problem can be transformed in the first approximation to buckling problem for the plate. The solution of the last problem for the narrow plate is found by the perturbation method.

For the shell with straight edges (Fig. 1a) the variables in PDE are separable, leading to ODE. If the shell has a slanted edge (Fig. 1b) then variables do not separated. However, the asymptotic integration method developed by P. E. Tovstik gives an approximate solution to the eigenvalue problem by reducing it to some eigenvalue problems for ODE. In the first approximation critical pressure for both shell coincide if $l_0 = l$.

# Effect of temperature gradient upon load induced thermal strain of heated, stressed concrete in transient state test

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The stress-strain constitutive relation of concrete subjected to thermomechanical loads is extremely complex since its deformation depends on the order in which the heat and loads are applied. Extensive experiments demonstrate that quasi-instantaneous load induced thermal strain, usually referred to as LITS, would develop upon the virgin heating of a mechanically pre-loaded concrete specimen. LITS is a special property unique to concrete among structural materials and any structural analysis of heated concrete that ignores it will yield erroneous results. However, the mechanism behind the LITS is not fully understood. The estimation of LITS is also not appropriately developed at present.

Theoretically, temperature-LITS curves should be achieved by obtaining homogeneous temperature fields through the specimen during whole process, while this is rarely achieved in practice and the effect of temperature gradient upon the test of LITS is always neglected. Except for that, the presence of a constant stress occurring in the loaded direction while heating and the temperature dependency of the mechanical properties couple the effect of solid and heat transfer, adding another dimension to the materially nonlinearity of the problem. Nevertheless, most existing models have not considered this amplified nonlinear mechanical strain individually away from LITS. In this report, numerical method is carried out to calculate the plastic strain caused by the combination of pre-fire load and temperature gradient in transient state test. By excluding this component from the existing elastic analysis, the effect of thermal gradient on LITS is quantified.

The finite element analysis shows that a strong stress fluctuation is activated in two opposite directions simultaneously due to the different expansions and degradation rate of mechanical properties resulted from the variation of temperature field in concrete specimen, which will not only influence the critical temperature, but also yield unloading residual plastic strain. The results indicate that using elastic analysis to calculate LITS is only reasonable at early stage and may lead to a miscalculation of LITS at relatively high temperature. The sharp increase of LITS beyond around 500℃ observed in many previous researches could be attributed to the implicit inclusion of enhanced plastic strain from thermal steady state, which should be separated thoroughly. According to the refinement of load induced thermal strain, a more convenient formulation involving fewer parameters is proposed to calculate LITS in a more accurate way. Finally, based on the corresponding parametric study, a tolerable maximum temperature difference (100 ℃) in a concrete specimen is suggested for practical experiment research.

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# EFFECTS OF TEMPERATURE-DEPENDENT MATERIAL PROPERTIES ON THERMO-MECHANICAL ANALYSIS OF IN-PLANE TWO-DIMENSIONAL FUNCTIONALLY GRADED CIRCULAR PLATES

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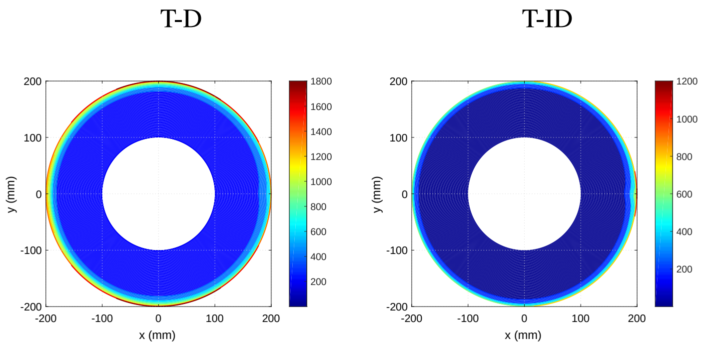


Figure 1: Distribution of the in-plane equivalent stress ($\sigma_{eqv}$) for n = 0.1 and m = 0.1 in the plate for T-D and T-ID cases

In this study, the effect of temperature-dependent material properties on the thermo-mechanical analysis of two-dimensional functionally graded hollow circular plates (2D-FGHCPs) was investigated. Finite difference equations were used in solving heat transfer and Naviers equations. The thermo-mechanical properties of FGHCPs were assumed to be vary with a power law along in-plane two directions, and temperature-dependent (T-D)/independent (T-ID). The compositional gradient exponent in the tangential direction was kept constant at m = 0.1. The compositional gradient exponents in the radial direction were taken as n = 0.1 (ceramic rich compound), 1.0 (linear change is from ceramic rich compound to metal rich compound) and 10.0 (metal rich compound). While the plate was subjected to an in-plane constant flux of $q_o = 200\ kW/m^2$ along its outer edge, the heat flux at the inner edge of the plate was zero and adiabatic boundary condition was assumed. Temperature distributions along the 2D-FGHCPs were not significantly affected in the T-D and T-ID cases, but the heat transfer time varied. The heat transfer time of T-D cases, were 1.344, 1.1915 and 0.9741 times higher than those of T-ID cases for n = 0.1, 1.0 and 10.0, respectively. As shown in Figure 1, the maximum equivalent stress levels of T-D case was 46.3% higher than this of T-ID case for n = 0.1. The maximum equivalent stress levels of T-D cases were 51.2% and 48.1% higher than those of T-ID cases for n = 1.0 and 10.0, respectively. This study emphasized that the necessity of taking into account the temperature dependence of material properties in residual stress analysis of functionally graded materials used at high operating temperatures.

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# CONTROL OF THERMOMECHANICAL ANISOTROPY OF HIGH SPEED ROTOR WITH PERMANENT MAGNETS IN MICRO ENERGY HARVESTERS

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Among the most innovative solutions to convert waste energy through harvesting systems, some microturbines are currently developed to be applied in gas pipelines and aqueducts, to scavenge energy from the main flow and supply power to some monitoring systems and sensors. Their technology resorts to classic turbine layout, but energy conversion is performed through some permanent magnets (PM) inducing current into fixed coils, as in PM switching flux motors [1,2]. This technology looks like a kinematic rotational scavenger, based on contactless electromechanical coupling, similar to some other ones, currently investigated within Vibration Energy Harvesting (VEH), where conversion is performed through some piezoelectric layers [3].

Basically, the flow acts on microturbine blades, and makes rotating the small rotor, being equipped with permanent magnets, coupled with stator through a magnetic induction phenomenon, as in bipolar PM motors [4]. As a structure, the energy harvester looks like a short massive disc rotor, with a central metallic core and a peripheral crown made by permanent magnets, whose polarization is just opposite, with respect of a main diameter (Fig.1). A critical problem, for the construction of rotor device, is that magnetic material exhibits a different thermal expansion along the two directions called *x* and *y*, respectively in Fig.1.

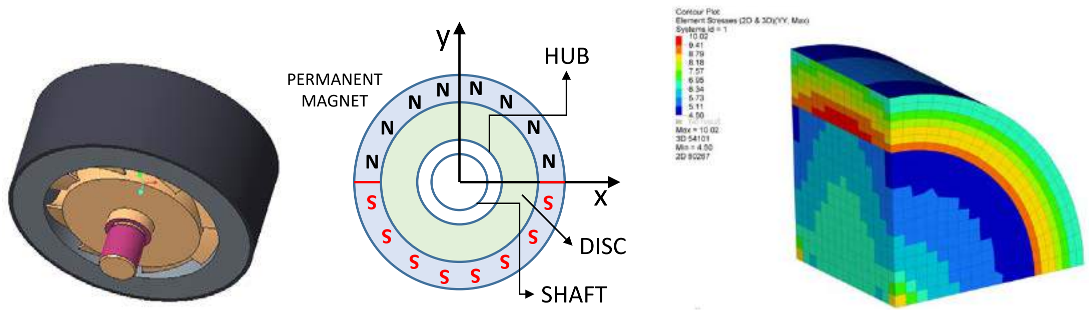


Figure 1 Sketch, front section and FEM results of a composite high speed rotor with permanent magnets under hoop effect of a carbon fibers thin belt.

This anisotropic behavior is emphasized when the flow acts on the rotor. Stress induced tends to make oval the neighboroughs of rotor, thus inducing an anisotropy, which leads to

# INTEGRATING ATOMISTIC AND MESOSCOPIC MOLECULAR SIMULATIONS AND INDUSTRIAL BUSINESS DECISIONS FOR NANOCOMPOSITE MATERIALS. THE COMPOSELECTOR EXPERIENCE

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The integration of modeling and simulations techniques to support material selection processes is one of the most compelling needs in advancing material industry and manufactory, due to the necessity of effective/efficient design and production of sophisticated materials, components and systems with advanced/extreme performance on a competitive time scale. In this arena and, specifically, for complex structural materials such as polymer-based nanocomposites (PNCs) there is a strong industrial demand for chemistry/physics-based models and modeling workflows able to predict relevant material properties (aka Key Performance Indicators or KPIs) in an accurate and reliable way.

In this area, this work aims at demonstrating the use in the EU H2020 project COMPOSELECTOR of a multi-disciplinary, multi-model approach for the accurate, reliable, efficient and cost-effective industry-driven KPIs determination for PNC materials, thereby filling the gap between business processes and materials science/engineering workflows. Specifically, the results obtained for case study pertaining to aerospace and automotive applications and the relevant KPIs determination (i.e., mechanical, viscoelastic and interfacial properties) will be presented and discussed.

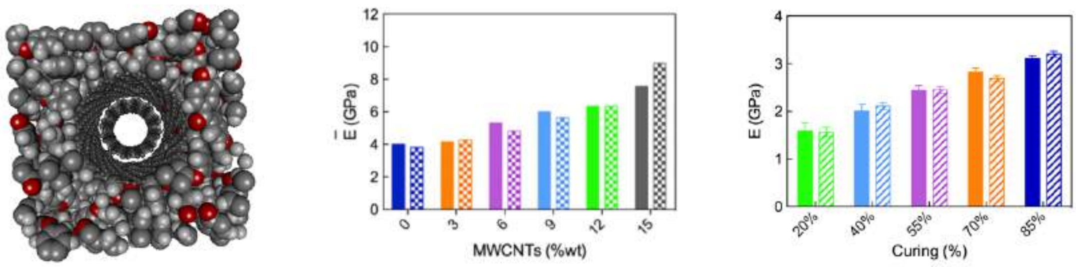


Figure 1 (Left) Atomistic model of a poly (ether ether ketone) (PEEK)/multi-wall carbon nanotubes (MWCNTs) PNC. (Middle) Comparison between simulated (patterned bars) and experimental (filled bars) values of the Young modulus for PEEK/MWCNT systems as a function of filler concentration (Mean average error = 0.45; Root mean standard error = 0.70). (Right) Comparison between mesoscopic (patterned bars) and atomistic (filled bars) simulated values of the Young modulus for a neat epoxy resin as a function the degree of curing.

# MULTISCALE MOLECULAR SIMULATIONS FOR NANOCOMPOSITE MATERIALS

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The main goal of computational materials science is the rapid and accurate prediction of properties of new materials before their development and production. In order to build new materials and compositions with designed new properties, it is essential to predict these properties before preparation, processing, and characterization.

Perhaps the most challenging task of physical, chemical, and engineering sciences is to develop computational tools for predicting structure and properties of complex materials (such a polymer-based nanocomposites, PNCs) from the knowledge of a few input parameters.

Accordingly, in this contribution we will present a new strategy of study of PNCs using multiscale molecular modeling (atomistic, mesoscale and finite element calculations) for the prediction of morphological, thermophysical, mechanical and transport properties, and for the development of theories and models for these high-performance materials.

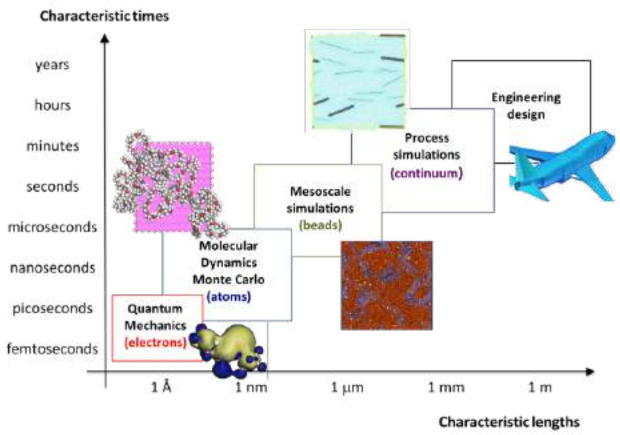


Figure 1 Hierarchy of multiscale molecular modeling techniques, showing approximate range of temporal and spatial scales covered by different categories of methods. Areas of overlap permit mapping or zooming from one scale to the next, which is often required for parameterization of higher scale methods or for obtaining a finer scale resolution of selected parts of the larger system.

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# LAYERWISE MIXED MODEL FOR ANALYSIS OF MULTILAYERED PLATES WITH EMBEDDED FUNCTIONALLY GRADED MATERIAL LAYERS

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Multilayered composite structures may exhibit troublesome effects due to the abrupt change of material properties across the layers interfaces, such as large interlaminar stresses that may cause damage. The concept of a functionally graded material (FGM) as an advanced composite material, wherein the composition of each material constituent varies gradually with respect to spatial coordinates, came to light to overcome these undesired effects. An FGM layer embedded in a multilayered structure may serve as a tailored interfacial zone with continuously varying material properties through the thickness direction, acting as a coating material to protect the core or inner structure.

This work presents a new layerwise model based on a mixed least-squares formulation for the static analysis of multilayered plates with embedded FGM layers. The model initially developed for multilayered composite structures with layers of constant material properties is now extended to include FGM layers of continuously varying material properties in the thickness direction. The model considers a layerwise variable description for displacements, transverse stresses and in-plane strains, chosen as independent variables. In doing so, the interlaminar $C^0$ continuity requirements due to compatibility and equilibrium conditions at the layers interfaces, where the material properties change, are fully fulfilled *a priori*, for all independent variables. For assessment purposes, the order of the in-plane two-dimensional finite element approximations and the order of the *z*-expansion through the layer thickness, as well as the number of layers, whether FGM layers or not, are considered free parameters. The added benefit of this model is its capacity to fully describe an FGM layer continuous variation of material properties in the thickness direction, for any given transition function, regardless of being defined in the form of exponential or polynomials functions. This is achieved by applying to the material characteristics a *z*-expansion through the layer thickness of a given order, set as an added free parameter, using a similar approach to the independent variables layerwise finite element approximations. The model predictive capabilities are assessed by comparison with three-dimensional exact solutions and close form solutions in the analysis of multilayered plates with embedded FGM layers subjected to transverse mechanical loadings. The numerical examples cover different configurations of multilayered plates, including as reference a single-layer FGM plate, with different side-to-thickness ratios and a series of degrees of material gradients within the FGM layers.

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# ON THE UNSYMMETRICAL BUCKLING OF THE NONUNIFORM SHALLOW SPHERICAL SHELLS UNDER INTERNAL PRESSURE

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The paper concerns the numerical study of asymmetric buckling of clamped nonuniform shallow spherical shells under internal pressure. The effect of material heterogeneity and curvature of a shell on the buckling load is examined. A mesh-like structure in a human eye called the Lamina Cribrosa (LC) may be modeled with such shell. The LC is a part of sclera, where the optic nerve fibres pass through and where the layer of sclera becomes thinner and many little pores appear. If microtubuli (pores) uniformly cover the entire shell then we may assume that the moduli of elasticity are constant. Generally, the number and size of pores are larger near the edge of the LC and, therefore, non-uniform shell with the modulus of elasticity decreasing away from the shell center could be used as a model. The buckling of the LC in the non-axisymmetric state in the neighborhood of the edge could cause edamas and folds at the periphery of the LC, atrophy of the optic nerve fibres and the eventual loss of the sight.

The refined 2D shell theory is employed to obtain the governing equations for buckling of clamped shallow spherical shells. The non-symmetric part of the solution is sought in terms of multiples of the harmonics of the angular coordinate. The numerical method is employed to evaluate the value of the lowest load, which leads to the appearance of the waves in the circumferential direction. It is shown that if the modulus of elasticity decreases away from the center of the shell, the critical internal pressure for non-symmetric buckling is significantly lower than for shell with constant mechanical properties and the number of waves in the circumferential direction increases with the degree of non-uniformity.

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# THREE-DIMENSIONAL ELASTIC WAVES IN MULTILAYERED PIEZOELECTRIC-ELASTIC COMPOSITES WITH NEGATIVE PERMITTIVITIES

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Multilayered piezoelectric-elastic composites are widely used in high-performed acoustic wave devices such as transducers, actuators and sensors, and the guided wave propagation in them are the theoretical basis for their working. Up to now, the decoupled out-of-plane (SH) wave and in-plane (P-SV) waves are the mainly focus for multilayered piezoelectric-elastic composites, and only the positive permittivities of constituent piezoelectric layers have been considered. In this paper, the coupled three-dimensional (3D) waves propagating in multilayered piezoelectric-elastic composites consisting of any numbers of piezoelectric or elastic laminates with arbitrarily anisotropy are studied analytically by the proposed method of reverberation-ray matrix (MRRM). Negative permittivities of the piezoelectric layers are also considered to introduce the new concept of negative index material into the design of multilayered acoustic wave devices. The formulation considers arbitrary direction of wave propagation and can calculate all kinds of dispersion curves. By considering all cases of negative and positive permittivities, comprehensive dispersion curves of 3D waves in several exemplified piezoelectric-elastic multilayers are provided. Novel dispersion characteristics in various cases of negative permitivities can be discerned by comparing all the counterpart dispersion curves, as shown in Figure 1 for an instance. The applicability of the proposed method at both low and high frequency ranges is also illustrated by numerical examples. The findings in this paper can be used to guide the design of innovative acoustic wave devices by introducing negative-indexed piezoelectric materials.

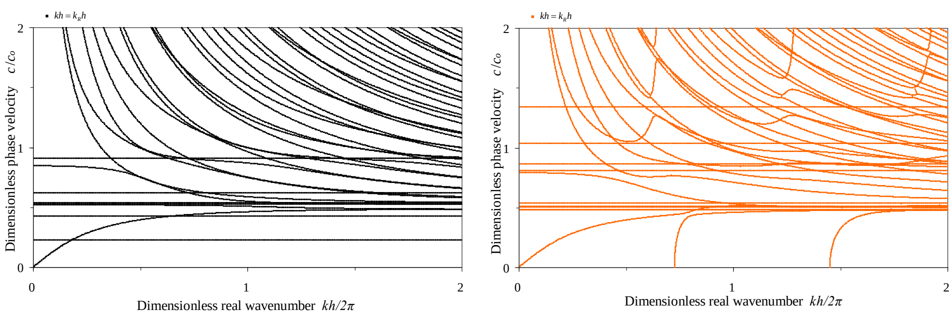


Figure 1 The wavenumber-phase velocity dispersion curves of a single piezoelectric layer of Barium Sodium Niobate (BSN) with negative and positive permittivities.

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# THREE-DIMENSIONAL FLOQUET WAVES IN PERIODICALLY MULTILAYERED ANISOTROPIC ELASTIC MEDIA

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Existing researches in periodically multilayered media mainly focus on the decoupled SH or P-SV waves. This paper theoretically analyzes the dispersion characteristics of coupled three-dimensional (3D) elastic waves in periodically multilayered media with the unit cell containing any numbers of layers with arbitrarily anisotropy. First, the formulation of the method of reverberation-ray matrix (MRRM) is proposed considering the Floquet-Bloch theorem for this purpose. Second, the dispersion equation is obtained for calculating the dispersion curves. Third, numerical examples are provided to illustrate the comprehensive dispersion curves for exemplified periodically multilayered anisotropic media with unit cell made of cross-ply laminates, from which the general features of the dispersion curves, as shown in Figure 1 for an instance, can be summarized. By comparing some of the frequency-wavenumber spectra with the counterpart results in existing literatures, we validate the proposed MRRM. The numerical stability and the superiority of the MRRM particularly over the transfer matrix method (TMM) are also illustrated by computing the dispersion curves in cases of large cutoff frequency.

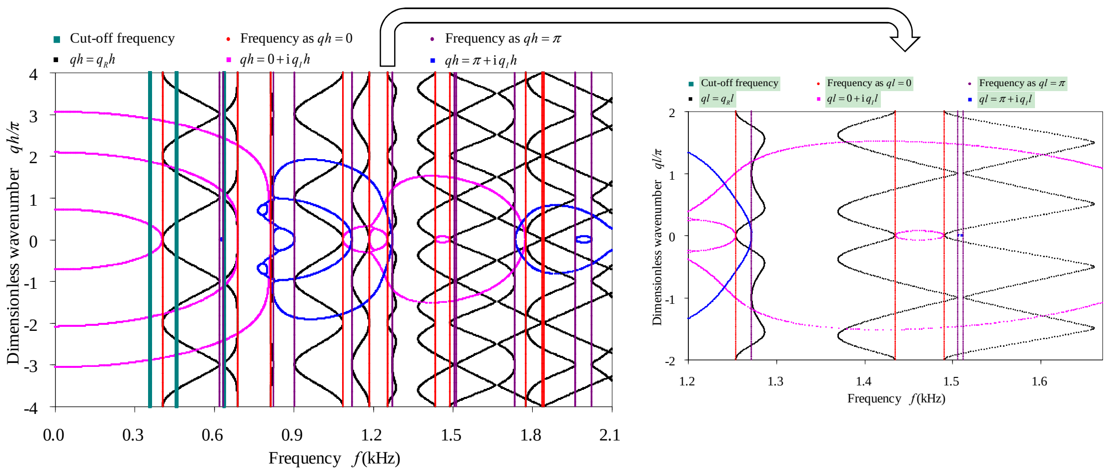


Figure 1 The first several dispersion curves of the 3D elastic waves along the thickness in exemplified periodically multilayered anisotropic media with the unit cell consisting of cross-ply laminates, as the dimensionless wavenumber in the layering $kh/\pi = 1.0$.

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# TRANSIENT RESPONSE OF AN INTERFACE CRACK BETWEEN PIEZOELECTRIC-PIEZOMAGNETIC LAYERED STRUCTURES UNDER MAGNETOELECTROMECHANICAL IMPACT LOADINGS

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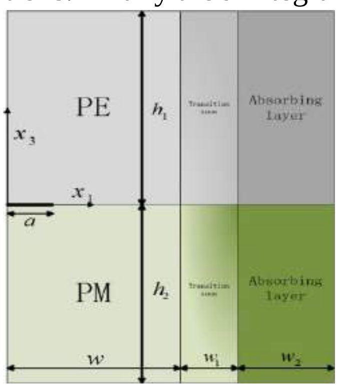
This paper studies the in-plane dynamic fracture problems of an interface crack between piezoelectric-piezomagnetic (PE-PM) layered structures under coupled electro-magneto-mechanical impact loadings by means of the extended finite element method (X-FEM) which possesses the inherent advantages in this problem and can avoid the complexities of analytical methods. In order to improve the accuracy of X-FEM, the more suitable crack tip enrichment functions are derived and utilized. Firstly, with a certain combination of piezoelectric and piezomagnetic materials, the asymptotic crack tip fields and the oscillating singularities are presented by using Stroh's formalism. Then, based on the asymptotic fields and singularities of crack tip, we develop the new enrichment functions for interface crack tip between PE-PM layered structure, which are applied to extend the generalized displacements and can exhibit the singularities of crack tip better. Substituting the generalized displacements presented by the modified enrichment functions into the weak-form of the equilibrium equations leads to the discrete system of equilibrium equations. Finally the J-integral is evaluated using the domain form of the contour integral.



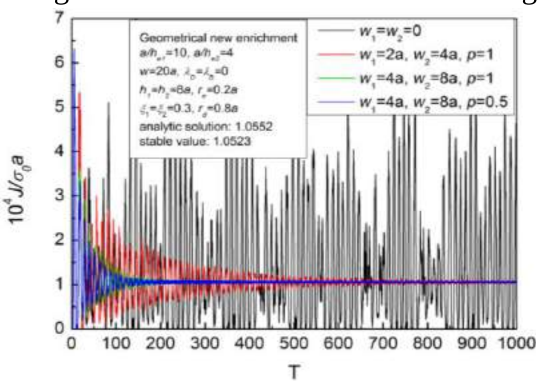




Fig.1. Problem configuration with absorbing boundary condition Fig.2. Time-domain responses of interface crack with absorbing boundary condition

To verify the validity and accuracy of the X-FEM, a modified Sarma absorbing boundary condition is presented to simulate the PE-PM infinite strips, the corresponding numerical results will be compared with the solutions which are obtained by analytical methods. By the numerical examples, the effects of applied loadings, time variables and structure geometries on the dynamic fracture properties will be discussed in detail.

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# A VARIATIONAL APPROACH TO BRITTLE FRACTURE AND INTERFACE DECOHESION IN COMPOSITES: THEORY AND APPLICATIONS

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An overview of recent advancements on the variational approach to fracture for the prediction of complex crack patterns in composite structures is herein proposed, as a result of the frontier research undertaken in the FP7 ERC Starting Grant project CA2PVM (http://musam.imtlucca.it/CA2PVM.html) focusing on the development of computational methods for the durability and the reliability assessment of photovoltaic laminates. From the methodological viewpoint, the nonlocal phase field approach to describe the propagation of brittle fracture in the bulk has been coupled with the cohesive zone model to depict interface crack growth events (Paggi and Reinoso, 2017), for 2D isotropic and anisotropic constitutive laws (Paggi et al., 2018), and also for 3D finite elasticity problems involving shells (Reinoso et al., 2017; Carollo et al., 2017). After a summary of the key aspects underlying the theoretical formulation and the finite element implementation using a monolithic fully implicit solution scheme in 2D solid finite elements and in 3D solid shells, an overview of the main technological applications involving layered shells, multi-material systems, and fracture in polycrystalline materials is provided. The examples are selected to show the capability of the proposed approach to investigate complex phenomena such as crack deflection vs. crack penetration at an interface, intergranular vs. transgranular crack growth in polycrystals, and interlayer vs. translayer failure in laminates. Experimental results are compared with numerical predictions for selected case studies relevant for Silicon-based photovoltaic applications.

M Paggi, J Reinoso (2017) Revisiting the problem of a crack impinging on an interface: a modeling framework for the interaction between the phase field approach for brittle fracture and the interface cohesive zone model. Computer Methods in Applied Mechanics and Engineering, 321:145-172.

M Paggi, M Corrado, J Reinoso (2018) Fracture of solar-grade anisotropic polycrystalline silicon: A combined phase field-cohesive zone model approach. Computer Methods in Applied Mechanics and Engineering, 330:123-148.

J Reinoso, M Paggi, C Linder (2017) Phase field modeling of brittle fracture for enhanced assumed strain shells at large deformations: formulation and finite element implementation. Computational Mechanics, 59:981-1001.

V Carollo, J Reinoso, M Paggi (2017) A 3d finite strain model for intralayer and interlayer crack simulation coupling the phase field approach and cohesive zone model. Composite Structures, 182:636-651.

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# STUDY ON THERMAL PROPERTIES OF THERMOELECTRIC $CoSb_3$ AND $Mg_2Si$ USING MOLECULAR DYNAMICS METHOD

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Molecular dynamics (MD) method is used to study the thermal properties of thermoelectric materials skutterudite $CoSb_3$ and $Mg_2Si$. The adopted crystal models of these two materials in this paper are verified by the simulations of the equilibrium states.
The thermal conductivity of two types of materials: $CoSb_3$ and $Mg_2Si$ are studied under different conditions. Ti filling rate, low-dimensionalization, and Mg vacancy proportion are selected as influence factors to investigate the variation of the thermal conductivity by using homogeneous non-equilibrium state simulation method.
The results show that the thermal conductivity of filled Ti atoms decreases obviously than single crystal $CoSb_3$.With the increase of the Ti filling rate, the thermal conductivity of $CoSb_3$ decreased. Otherwise, the thermal conductivity of $CoSb_3$ nanowire is least, and $CoSb_3$ bulk has the greatest thermal conductivity when the other conditions are the same. And for $Mg_2Si$, the thermal conductivity is decreased with the Mg vacancy proportion increase. The same conclusion of thermal conductivity in three forms of $Mg_2Si$: nanowire, nanofilm and bulk is found. It is found that the low-dimensionalization of the thermoelectric material can effectively reduce the thermal conductivity and improve the thermal performance.

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# COMPARISON BETWEEN ERINGEN'S DIFFERENTIAL NONLOCAL MODEL AND LAPLACE'S FRACTIONAL OPERATOR APPROACH

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Several approaches have been proposed to describe the behavior of nano-structures and composites. Among these the nonlocal elasticity, proposed by Eringen, appears a very useful tool. According to Eringen [1], the nonlocal elastic behavior can be described by the following relation between stress and strain

$$t_{kl}(x) = \int_V \alpha(|x' - x|, \tau)\sigma_{kl}(x')dv, \quad \text{with } \sigma_{kl}(x') = \lambda \epsilon_{rr}(x')\delta_{kl} + 2\mu \epsilon_{kl}(x') \qquad (1)$$

The formula shows that the stress at a point depends not only on the strain at that same point but also on the strain at distant point. One approach in dealing with the Eringen's formula is to manipulate the equations in order to obtain a system of classical differential equation. An alternative approach is to treat the function $\alpha$ in (1) as a kernel and this lead to a fractional differential model [2, 3]. Moreover, an equation involving the fractional Laplacian operator can also be obtained, as shown in [4]. This latter model has been used to analyze the response of a rod with nonlocal behavior to an external distributed load. In particular, the effect of the different model parameters involved, especially the order of the fractional derivative, on the response has been investigated [5].

In the present work we compare the nonlocal rod model involving the fractional Laplacian operator with the model based on integer differential equations, in order to establish a relation with the different nonlocal parameters involved in the two models.

*References*

1. Eringen A.C. "On differential equation of nonlocal elasticity and solutions of screw dislocation and surface waves" J. Appl. Phys. 54 (1983), 4703-4706.
2. Sapora A., Cornetti P., Carpinteri A. "Wave propagation in nonlocal elastic continua modelled by a fractional calculus approach" Commun. Nonlinear Sci. Numer. Simul. 18 (2013), 63–74.
3. Di Paola M., Zingales M., "Long-range cohesive interactions of nonlocal continuum faced by fractional calculus" Int. J. Solids Struct. 45 (2008), 5642–5659.
4. Autuori G., Cluni F., Gusella V., Pucci P. "Mathematical models for nonlocal elastic composite materials" Adv. Nonlinear Anal. 6 (2017) , 355-382
5. Autuori G., Cluni F., Gusella V., Pucci P. "Effects of the Fractional Laplacian Order on the Nonlocal Elastic Rod Response" Asce-Asme J. of Risk and Uncertainty on Engineering Systems Part B-Mechanical Engineering, 3 (2017), 030902-1 - 030902-5

# LARGE AMPLITUDE VIBRATIONS OF PRE-STRESSED PIEZO-ACTUATED CIRCULAR PLATES

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The market for mobile speakers might see a revolution by digital sound reconstruction. Here, the audible sound is produced by the superposition of pulses from an array of micro-speakers. This, so called speaklets, are MEMS devices. For the design of such systems the correct modelling of the actuator is essential.

The investigated system consists of a circular plate-like structure with a diameter of several hundred micro meter. It is composed of several layers of different materials, typically a substrate, electrodes, and an active piezo layer. The total thickness of the plate is in the range of several micro meters, thus we're considering a thin plate. In order to account for large displacements we adopt the Fppl-von Karman assumption. All materials are modelled as linear-elastic, with optional linearised piezoelectric coupling and thermal expansion, to take actuation and pre-stress into account.

We study large amplitude vibrations by assuming harmonic forcing and a multi harmonic response, i.e. we apply the harmonic balance method. With the additional assumption of rotational symmetry, this allows to reduce the non-linear plate equations to a system of non-linear ordinary differential equations. We then solve the system of equations by a collocation based boundary value problem solver. This allows to study the system dynamics by computing non-linear transfer functions or to solve the free oscillation eigenvalue problem, thus obtaining the amplitude-dependent natural frequencies and mode shapes. Eventually, we also investigate spatially shaping the electrode pattern in order to obtain the desired actuator performance.

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# Nonlocal modeling of elastic nano-structures

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Mechanical modeling of nano-materials and nano-structures is a subject of ever and ever increasing interest in scientific literature due to challenging tasks in theoretical formulations and computational methodologies. Carbon nanotubes and graphene sheets are widely investigated for the development of modern nano-devices.

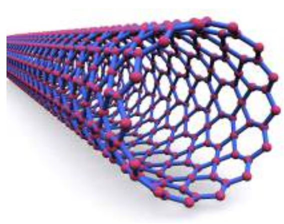

Figure 1: Carbon nanotube.

The realization of ground-breaking nano-sensors and nano-actuators, as basic structural elements of scanners, mirrors, gyroscopes, springs and many similar other nanoscale systems, is an important target with countless conceivable applications. Nano-materials perform also as excellent components for reinforcement in composite nano-structures. Small-scale structural modeling of 1D, 2D and 3D continua is conveniently resorted to in place of atomistic approaches. Several nonlocal models have been proposed in literature and are being extensively investigated. Comparisons with lattice dynamics and wave propagation phenomena have been exploited. Basic difficulties and paradoxical results have been faced by the standard strain-driven approach, as evidenced by scholars. Several attempts to overcome the relevant issues have been proposed. A new modeling has been recently contributed with the aim of providing an effective strategy for the analysis of nonlocal continuous problems. The main idea consists in adopting a stress-driven integral constitutive law instead of the usual strain-driven one. The roles of stress and elastic strain fields are thus swapped in the governing integral convolution, with the new law not the inverse of the former. This line of research is promising in getting enhanced theoretical models and robust numerical methodologies based on nonlocal continuum mechanics. Improvement in the current state of the art and design of simple and reliable engineering tools for nano-technological applications are the main goals.

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# A non-iterative method for designing topologically efficient buckling-resistant structures

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Lightweight buckling resistant structures are widely employed in many modern applications, *e.g.* aerospace, automotive or wind energy technology. Therefore, finding the topology that maximises the buckling load given a mass or alternately, minimising the mass given a load, is of great importance. Analytical solutions are not always available, therefore iterative optimisation algorithms, such as Gradient or Genetic Algorithms, are widely employed. These processes can be complicated and time consuming, especially during initial stages of the design. Moreover, for some cases, improved, yet sub-optimal, solutions may be sufficient. Having this in mind, we propose a new non-iterative and intuitive method that can be used to reduce the mass of a structure without affecting (*e.g* less than 1%) its buckling load or alternatively increasing the buckling strength keeping the mass constant. A uniaxially loaded square flat plate, with different boundary conditions (clamped edges, simply-supported edges and one-edge clamped), is considered. Our method shows similar results compared with those in the optimisation, with less computational effort.

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# STICK AND SLIP PIEZO MOTORS MODELLING

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Modular Stepping Piezo Actuators (MSPA) use the stick-slip principle to combine high resolution positioning (<µm) with long stroke (>cm). These motors provide unlimited motion in both rotation and translation. Fine mode allows precise positioning (<10nm). Since it is a module, it easily fits any existing devices requiring up to 25N of driving force with a speed up to 50mm/s.

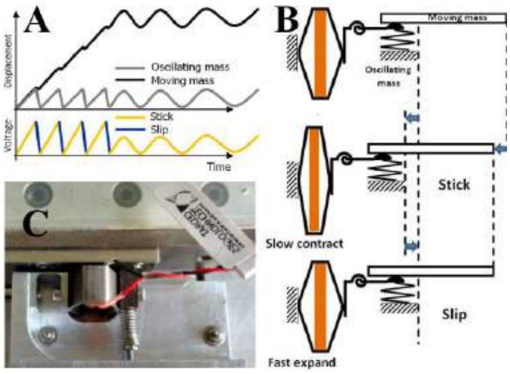


Figure 1 MSPA motor: A- Stick-Slip principle, B-scheme and C- preliminary breadboard

This motor module benefits the use of space qualified Amplified Piezo Actuators (APA®). It is then deemed a good candidate for severe environments such as vacuum, cryo, vibrations, nonmagnetic etc…

This paper presents technical challenges encountered for the design of stick and slip piezo motors. A focus is provided regarding the differences between two stick and slip piezo motors developed by Cedrat technologies: the MSPA (figure 1) Versus the Linear Stepping Piezo Actuator (LSPA).

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# STRUCTURAL (MULTIELEMENT) MODEL WITH THE THERMOMECHANICAL EXPOSURE MEMORY

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The structural multielement model with the thermomechanical exposure memory for the polymeric materials presented. Also, this model can consider other effects such as moisture shrinkage. The memory on the thermomechanical exposure demonstrates itself in the polymeric material structures subjected to the mechanical loading with simultaneous technological or climatic temperature changing.

The model consists of unit cells composed of the three-element models that include the same elastic and viscoelastic elements. In so doing every single cell is turns on or off by the special temperature-sensitive brake which response at a certain temperature, so that give a chance to consider the thermomechanical memory. The thermic modification of elastic and rheologic parameters is modelled only by the number of turned on cells, which have a uniform experimentally determined parameters.

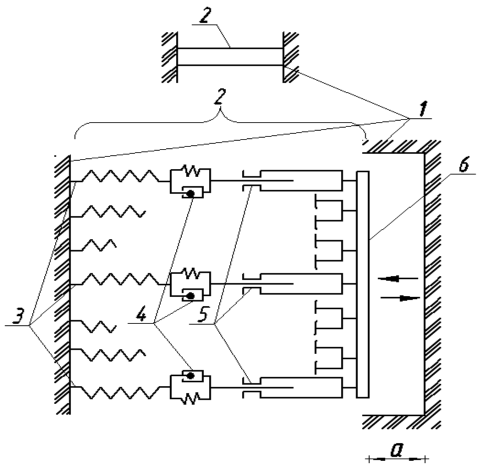


*Figure 1 Presented mechanical model of the thermoplastic rod with fixed ends in the nondeformable frame*

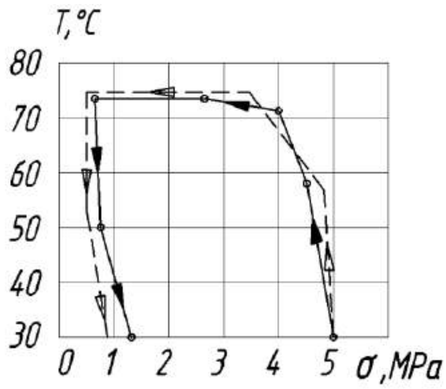


*Figure 2 Comparison of the experimental (continuous line) and calculated (dashed line) results of the PVC rod at nonisothermic loading*

Modelled thermoplastic rod (2) with the fixed in the nondeformable frame (1) ends scheme is shown in the figure 1. Unit cell of the model includes elastic elements (3); viscoelastic elements (4); temperature brakes (5); slider (6). The displacement of a slider corresponded to unrealized thermal deformation designated as (a). At the cooling process temperature brakes (5) turns on unit cells alternately and turns off at the heating process. The rigidity of the thermoplastic rod at the certain temperature is proportional to the number of cells which turned on.

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# An Exact Dynamic Stiffness Method Incorporating Rayleigh-Love Bar and Timoshenko Beam Theories for Free Vibration Analysis of Plane Frames

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An accurate free vibration analysis is carried for plane frames in the low, medium and high frequency ranges by applying the method of dynamic stiffness matrix. In order to achieve this objective, the dynamic stiffness properties of each member of the frame are derived by using the Rayleigh-Love bar theory for the axial stiffnesses and Timoshenko beam theory for the bending stiffnesses. These stiffnesses are assembled in the usual way to obtain the frequency dependent overall dynamic stiffness matrix of the final frame, leading to the generally adopted customary eigenvalue problem which is solved by applying the well-known Wittrick-Williams algorithm. Results are computed for a number of wide ranging plane frames. A detailed parametric study is carried out by varying significant frame parameters to investigate the effects of lateral inertia arising from the application of Rayleigh-Love bar theory and also the effects of shear deformation and rotatory inertia arising from the application of Timoshenko beam theory. The errors incurred as a consequence of using the classical Bernoulli-Euler bar and beam theories as opposed to the corresponding Rayleigh-Love and Timoshenko theories are assessed and circumstances when large differences in results can occur, particularly in the high frequency range are critically examined and commented on. Some representative mode shapes are also presented. Significant conclusions are drawn on the effectiveness of using Rayleigh-Love and Timoshenko theories and the deficiencies of the classical Bernoulli-Euler theory are identified. As it is well known, Statistical Energy Analysis (SEA) requires modal densities within the entire frequency range comprising low, medium and high frequencies and it is in this context, the theory developed and the analysis carried out are expected to be most useful.

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# MULTI-SCALE MODELING OF HETEROGENEOUS ELASTIC SOLIDS BASED ON CONTROL OF MODELING ERRORS IN LOCAL QUANTITIES OF INTEREST

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We consider the analysis of the mechanics of multiphase composite materials. Such materials generally exhibit very complex microstructure with highly oscillatory material properties. It is prohibitive to resolve all the features of the microstructure in a computational process. Classical approaches have therefore focused on methods of homogenization, generally based on the assumption that the microstructure of the media is periodic or on techniques for determining effective properties of representative volume elements. These averaged material models cannot account for local micromechanical effects that are critical factors in determining the behavior and service life of structural components. To resolve this issue, Oden et al. developed the Goal-Oriented Adaptive Modeling (GOAM) method. It represents a systematic approach for adaptive multi-scale modeling of heterogeneous materials based on control of the modeling error in a local quantity of interest (i.e. goal) of the material response that is specified by the user. The basic idea is to start with an initial analysis based on homogenized properties that are obtained via the classical averaging techniques. The homogeneous surrogate model is then enhanced in an iterative process of including the material microstructure in a local area surrounding the quantity of interest that increases in size with every iteration step. A critical element in the GOAM method is the ability to accurately estimate the modeling error. Currently, this is established by providing a residual-based a posteriori error estimator. It involves solving for a global influence function, related to the quantity of interest, and subsequently computing global integrals of governing residual functionals. In the case of multiphase composite materials, this estimation process can be computationally prohibitive, again due to the complexity of the microstructure. Hence, we propose a new technique for local, goal-oriented estimation of the modeling error that resolves this computational issue. It is based on a local variational approach and therefore requires computing a local influence function and local residual integrals at low computational cost. We introduce this new approach for the multi-scale analysis of linear elastostatics problems of multiphase composites and the investigation of linear local quantities of interest of the material response.

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# SIZE DEPENDENT BENDING, BUCKLING AND FREE VIBRATION OF TWO DIRECTIONAL FUNCTIONALLY GRADED MICROBEAMS BASED ON THE MODIFIED COUPLED STRESS THEORY AND A UNIFIED FORMULATION

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The bending, buckling and free vibration of two directional functionally graded (2D-FG) microbeams is investigated using a one-dimensional refined finite element model based on a Unified Formulation. The material properties are assumed to vary through the thickness and longitudinal axis and follow the power-law distribution. To take size effect into account, a modified coupled stress theory is incorporated into the beam theory. Governing equations and corresponding boundary conditions are derived employing Hamilton's principle. A detailed parametric study is performed to indicate the influences of aspect ratios, gradient indexes and boundary conditions on the behavior of 2D-FG microbeams. The results show that the one-dimensional non-local beam model based on a Unified Formulation can accurately predict three-dimensional results with a lower computational cost.

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# Indentation tests of two-dimensional materials with substrates

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Many important applications are based on the performance of 2D-materials mounted on the different substrates, and the stability of these applications is closely related to the mechanical behaviors of 2D-materials binding with substrate, including silicon dioxide, PET and PDMS. For the structure of 2D-materials/substrate, the thickness of 2D-materials is ultra-low, and the typically indentation depth range used in experiments is high, and thus the ratio of $\delta/t$ is around 1000, which is more than 300 times of that used in the conventional thin-film/substrate systems. Therefore, the existing indentation models as well as findings might be not effective for the composite structure of graphene/substrate.

The primary objective of present work is to understand the effect of the ratio of the elastic modulus of 2D-material to that of the substrate ($\lambda$) on the indentation deformation of the composite structure (2D-material/substrate). Indentation behavior of two-dimensional (2D) materials mounted on the substrates with varying stiffness is investigated using finite element method (FEM). It is found that with the increase of $\lambda$, the deformations of both 2D-material and substrate become less localized; the contact area rapidly decreases with $\lambda$, which cannot be properly predicted by the classic indentation models. Therefore, for a large value of $\lambda$ (e.g., $\lambda > 10^4$), the existing indentation models are not able to properly describe the indentation response of 2D-material/substrate. In addition, due to an ultra-low thickness of 2D-material, the indentation behavior of 2D-material/substrate is mainly controlled by the substrate properties when $\lambda$ is lower than $10^3$; whereas the ratio of the strain energy of 2D-maerial to that of the overall strain energy rapidly increases $\lambda$, which will reach the peak value of 1/3 at $\lambda = 10^6$. Therefore, for a high $\lambda$, it is possible to determine the elastic modulus of 2D-material from the overall indentation response of 2D-material/substrate by the inverse analysis with the help of FEM.

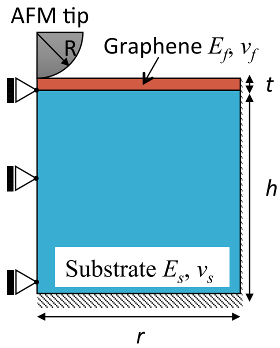


Figure 1 Schematic of the indentation test of 2D-material/substrate.

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# INTERNAL RESONANCES IN DYNAMICS OF NONLINEAR PLATES

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Recently nonlinear free vibrations of a thin plate described by three coupled nonlinear differential equations in terms of two in-plane displacements and deflection have been considered when the plate is being under the conditions of the internal resonance, resulting in the interaction of modes corresponding to the mutually orthogonal displacements [1]. The procedure resulting in decoupling linear parts of equations was proposed with further utilization of the method of multiple time scales for solving nonlinear governing equations of motion; in so doing the amplitude functions were expanded into power series in terms of the small parameter and depend on different time scales.

Comparison of the results obtained in [1] via the new suggested procedure with those for a nonlinear plate, the motion of which is described either by one equation in terms of plate's deflection [2] or also by three coupled nonlinear equations in terms of three displacements but without decoupling the linear parts of governing equations [3], reveals the fact that the new approach allows one to discover and analyze much more diversified variety of internal resonances than all other existing previously in literature approaches.

In the present paper, the approach suggested in [1] has been generalized for investigating nonlinear free vibrations of plates, equations of motion of which take the rotary inertia and shear deformations into account and involve five coupled nonlinear differential equations in terms of three mutually orthogonal displacements and two angles of rotation. It has been shown that the analytical approach proposed in [1] could be used in this case as well, since the matrix of the natural modes coupled by the internal resonance is the Hermitian matrix (i.e., it is symmetric and all its elements are real). The utilized plate model provides much more possibilities for the occurrence of the internal or combinational resonances, which have been revealed and classified.

This research was made possible by Grant no. 9.5138.2017/8.9 as a Government task from the Ministry of Education and Science of the Russian Federation.

References

1. Rossikhin, Yu.A., Shitikova, M.V. and Ngenzi, J.Cl., A new approach for studying nonlinear dynamic response of a thin plate with internal resonance in a fractional viscoelastic medium, Shock and Vibration, 2015, Article ID 795606, 28 pages (2015).
2. Ribeiro, P., Petyt, M., Non-linear free vibration of isotropic plates with internal resonance, Int. J. Non-Linear Mech., 35, 263-278 (2000).
3. Rossikhin, Yu.A., Shitikova, M.V., Analysis of free nonlinear vibrations of a viscoelastic plate under the conditions of different internal resonances, Int. J. Non-Linear Mech., 41, 313-325, (2006).

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# GRAPHENE COATING TO ENHANCE TRIBOLOGICAL PERFORMANCE OF STEELS

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Wear damage, and in particular, fretting wear is one of the most problematic failure modes of mechanical components as this phenomenon is not easy to be considered during the component design. Fretting damage affect the machine reliability, efficiency and safety, increasing the maintenance and operating costs. One of the most important parameters affecting this phenomenon is the coefficient of friction (CoF) of the materials in contact. Moreover, a reduction of CoF brings to an increase in machine efficiency. The aim of this work is to investigate the application of graphene to reduce the CoF of mechanical components and consequently to reduce the risk of wear damage. The use of graphene as covering material to reduce CoF and wear is not well explored in the literature. In this work, graphene has been applied on C40 steel samples using different coating procedures (direct coating and transferred graphene coating). Tribological performance have been evaluated in terms of CoF and worn volume by means of pin on disk test, comparing the results obtained of no coated samples with coated ones (Figure 1a shows an example of coated sample after pin on disk test).

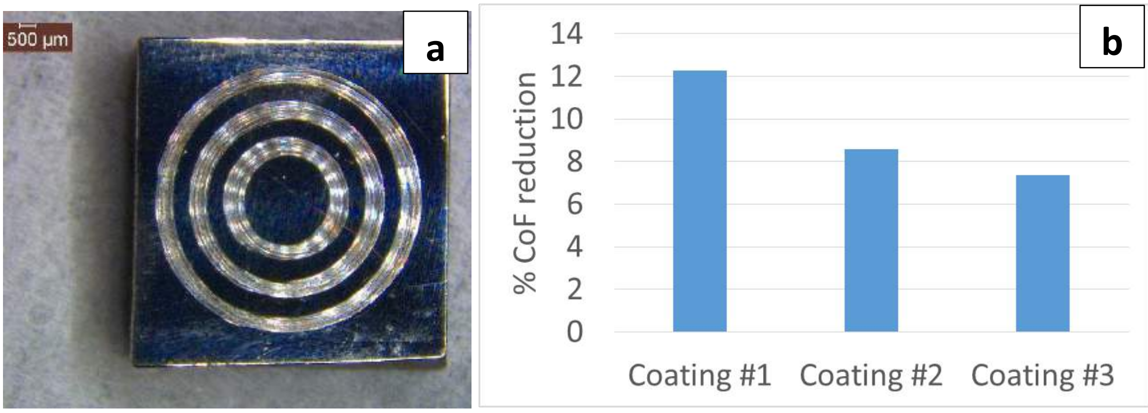


Figure 1 Graphene coated steel sample after pin on disk test (a) and CoF reduction obtained by graphene coatings (b).

Results are promising, showing that graphene coatings reduce both COF (Figure 1b) and wear coefficient.

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# A STUDY OF INTERFACIAL PROPERTY OF COMPOSITE BASED ON ENERGY–BASED DEBONDING CRITERION

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This paper presents a theoretical analysis for the single-fiber pullout with unload process based on the energy-based debonding criterion and the modified analysis of stress transfer between fiber and matrix. The relationship between the applied stress and the interfacial relative displacement is presented and it has been expressed as a function of the radial residual thermal stress, fiber pullout rate and volume content as well as the length of reverse frictional sliding. At the same time considered the influence of fiber pullout rate on interfacial frictional coefficient. Using the previous research results, a series of calculation results have been obtained and the numerical results show that the applied stress result in further debonding increases with the decrease of the fiber pull-out rate and the increase of the fiber volume content and the radial residual thermal stress. When the interface debonding close to the model length a drop for the applied stress will appear and the drops of short models are larger than those of long models. Under different conditions, the length of the model hardly affects the debonding and reverse sliding in unloading processes at the initial debonding region. This study reviews the effect of the fiber pull-out rate and radial residual thermal stress and also the fiber volume content on the applied stress result in further debonding increases.

# BUCKLING INDUCED THREE-DIMENSIONAL ORIGAMI STRUCTURES AND THEIR APPLICATIONS

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Origami assembly is a topic of growing interest both in the scientific and engineering communities due to the potential applications in a broad range of areas. Recently reported approaches that exploit the controlled, compressive buckling of 2D precursors offer the versatilities in material selection, processing dimensions and shape controllability, thereby representing promising avenues to autonomic origami assembly. A spatially non-uniform distribution of thickness in the 2D precursors is required in these approaches to induce strain localization at desired folding creases. Development of inverse-problem algorithms that can yield the crease distributions and folding sequences to achieve desired 3D structure represents an essential aspect in this area. One of those studies, for example, utilize the concept of lattice kirigami, which is a variant of origami and involves both the cutting and folding, to realize the complex 3D structures. In current literatures, the 3D origami structures induced by compressive buckling are restricted by soft elastomeric substrate which limits their potential applications.

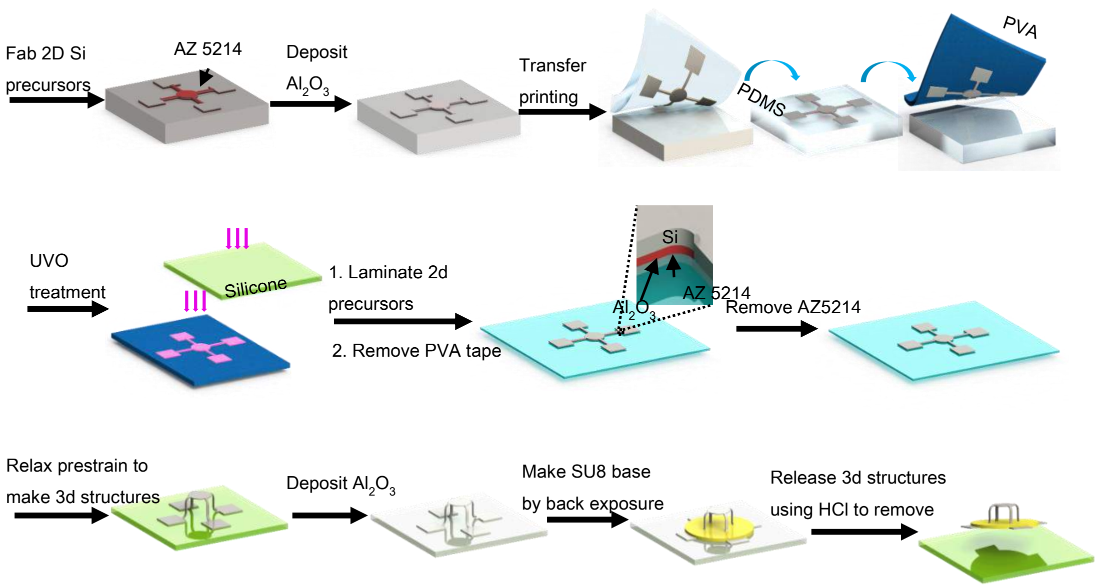


Figure 1 Main steps of the fabrications for freestanding mesostructures

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# ANALYSIS OF FSI-DRIVEN ENERGY HARVESTING DEVICES USING PARAMETERISED REDUCED-ORDER MODELS

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A specific class of energy harvester devices for renewable energy resources allows conversion of ambient fluid flow energy to electrical energy via flow-induced vibrations of a piezo-ceramic composite structure positioned in the flow field. This energy converter technology simultaneously involves the interaction of a composite structure and a surrounding fluid, the electric charge accumulated in the piezo-ceramic material and a controlling electrical circuit. In order to predict the efficiency and operational properties of such future devices and to increase their robustness and performance, a mathematical and numerical model of the complex physical system is required to allow systematic computational investigation of the involved phenomena and coupling characteristics.

The presentation will discuss a monolithic modelling approach that allows simultaneous analysis of the harvester, which involves surface-coupled fluid-structure interaction, volume-coupled electro-mechanics and a controlling energy harvesting circuit. Based on a finite element discretisation of the weighted residual form of the governing equations, time- and frequency-domain analysis enables investigation of different types of structures (plate, shells) subject to exterior/interior flow with varying parameters, and attached electrical circuits with respect to the electrical power output generated. Consequently, options for parametric reduced-order modelling of flow-driven energy harvesters will be discussed.

## References

[1] S. Ravi, A. Zilian, Time and frequency domain analysis of piezoelectric energy harvesters by monolithic finite element modeling, Int. J. for Numerical Methods in Engrg, 112(12):1828–1847, 2017.

[2] S. Ravi, A. Zilian, Monolithic modeling and finite element analysis of piezoelectric energy harvesters, Acta Mechanica, 228(6):2251–2267, 2017.

[3] S. Ravi, A. Zilian, Numerical Modeling of Flow-Driven Piezoelectric Energy Harvesting Devices, in: Computational Methods for Solids and Fluids, Springer, 2016.

# NONLINEAR MODELING OF DIELECTRIC ELASTOMER ACTUATORS ACCOUNTING FOR ELECTROSTRICTION AND POLARISATION SATURATION

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Extending the family of smart materials from brittle ceramic based materials to soft polymer based materials motivates the research in the field of electroactive polymers (EAPs). Inherent to the employment of EAP actuators (operation at large displacement fields) is the need for large electric fields and typically very thin application designs, because of the polymers low elastic modulus. For this reason, the application of a structural mechanics framework, modeling EAP plates and shells as a material surface is beneficial.

Starting with the three-dimensional set of nonlinear field equations, a classical free energy function is extended to an enhanced electro-mechanically coupled form by means of a multiplicative decomposition of the deformation gradient tensor. The resulting energy function is composed of a pure mechanical energy and a mixed electro-mechanical energy. This allows for an elegant incorporation of any established hyperelastic material function by means of the specific form of the pure mechanical part, while any constitutive electro-mechanical coupling is incorporated through the multiplicative decomposition. Moreover, the mixed electro-mechanical part accounts for both, polarisation as well as polarisation stress. In this talk we take two separate constitutive phenomena under consideration: electrostriction and polarization saturation, and consolidate actuation stability by introducing charge driven operation.

Based on the three-dimensional constitutive equations, the structural two-dimensional counterpart is derived by imposing a plane stress condition together with the incompressibility condition of the polymer. The resulting structural two-dimensional energy function for EAP plates and shells preserves the decomposed, pure mechanical and mixed electro-mechanical nature. We complete the paper by presenting numerical results obtained by a nonlinear finite element analyses. Results show good agreement with other numerical as well as experimental results presented in the literature, coming along with the efficiency and accuracy of the structural mechanics framework.

# GEOMETRICAL RECONSTRUCTION OF CONCRETE MATERIALS THROUGH THE AID OF ADVANCED MEASUREMENT TECHNIQUES AND STUDIES OF THEIR MECHANICAL BEHAVIOR

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In this paper the mechanical behaviour of concrete materials is investigated, strictly comparing experimental evidences and numerical results on specimens subjected to uniaxial tests. The analyses are performed at the mesoscale level, distinguishing between cement paste and aggregates.

Compelling issues for the modelling phase need to be addressed, in order to obtain models as much as close as possible to the experimental samples; i.e. the accurate reproduction of the external geometry of the aggregates added to the concrete mix design and their random disposition in the sample. For this purpose, solid models are created through the adoption of 3D advanced measurement techniques, such as laser scanners or industrial computer tomography (CT), while ad-hoc random algorithm has been developed to place and orient the inclusions by satisfying their volume ratio and the grading curve.

In order to study numerically the mechanical behaviour of concrete samples, under uniaxial compression tests, a specific elasto-plastic-damaged formulation has been implemented [1]. In particular the plasticity model is based on Menétrey-Willam [2] plastic surface, where the yield surface is described in function of the second and the third deviatoric invariant of the stress tensor, while the scalar isotropic model by Mazars is considered for damage [3].

A specific constitutive behaviour has been assigned to each constituent; the cement matrix is characterized as an elastic-plastic material with damage capabilities while the aggregates are assumed to behave elastically.

REFERENCES

[1] G. Mazzucco, G. Xotta, B. Pomaro, V.A. Salomoni, F. Faleschini, "Elastoplastic-damaged meso-scale modelling of concrete with recycled aggregates", Composites Part B: Engineering, 140, 145-156 (2018).
[2] P. Menétrey, K.J. Willam, "Triaxial failure criterion for concrete and its generalization", ACI Struct. J., 92(3), 311-318 (1995).
[3] J. Mazars, G. Pijaudier-Cabot, "Continuum damage theory application to concrete", J. Eng. Mech.-ASCE, 115(2), 345-365 (1989).

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# Overview on metamaterials for acoustic applications

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The increasing requirement for bigger, faster and lighter vehicles has increased the demand of efficient structural arrangements, making sandwich constructions a well-established technique in lightweight component design. The weight reduction can be used to increase the payload, to increase the speed or just to reduce the energy consumption with maintained loading capability and/or max speed. However, lightweight design typically combines reduced weight and increased stiffness, leading to a deterioration of the noise and vibration attenuation performance. Consequently, merging lightweight and vibro-acoustic requirements results in a challenging and often conflicting task, for which novel low mass and compact volume solutions are sought.

New ideas, coupled with the expanding technologies of computational simulation and additive manufacturing, will produce the next generation of materials. Metamaterial is just this: a new concept, a new technology which properties derive not from the nature of the material itself but by from their newly designed structures. Their precise shape, geometry, size, orientation and arrangement gives them their smart properties capable to manipulate waves: by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with conventional materials.

Metamaterial is a combination of ”meta” and ”material”. Meta is a Greek word which means *something beyond, altered, changed*. To the letter metamaterial means: *material that does not exist in nature*; in physics *material with negative refractive index*.

Metamaterials found great interest in several applications for manipulating waves. First prototypes were built to manipulate electromagnetic waves at the end of the 19th century. Recently, metamaterials have found a great interest in vibro-acoustic field with favorable noise and vibration attenuation behavior, at least in some targeted and tunable frequency ranges, referred to as stop bands. Acoustic metamaterials (AMMs) are artificial structures made of subwavelength units such that their acoustic properties are new in comparison with that of the building units. Recent studies show that heterogeneous, poroelastic metamaterials can achieve considerable wave and/or vibration energy absorption. For instance, randomly embedding solid, metal inclusions into poroelastic foams improves the low frequency attenuation of the host media. Periodically distributing such inclusions also spawns bandgap phenomena to substantially increase low frequency vibroacoustic energy absorption via ”trapped” mode effects.

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# VIBRATIONAL SPECTRA OF THIN ELLIPTIC PLATES

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Thin plates of different shapes are used as structural components in almost all engineering applications, where high strength, stiffness and light weight materials are highly needed. The aim of this research is to study free transverse vibrations of an elliptic thin plate with a varying eccentricity and a plate with an elliptic cutout with the same eccentricity. Plates of such shape are widely used not only in engineering but also in biomechanical modeling. For example, for all human eyes the Lamina Cribrosa (anatomical structure) appears as an elliptical plate with multiple holes.

Both analytical and numerical methods are used to examine the problem. The analytical solution is represented as a combination of Mathieu functions. For plates with small eccentricity and/or small central elliptic cutout asymptotic methods are used to describe the effect of the eccentricity and cutout on the vibrational spectra.

The difference between vibrations of a circular and an elliptic plate is the following. For a circular plate a vibrational mode can be expressed by one particular solution of the differential equation governing vibrations, for an elliptic plate all appropriate particular solutions should be summed up to express even one vibrational mode. One should remember it when consider the perturbation of the vibrational spectrum of a circular shell with nonzero eccentricity.

For elliptic plates of constant thickness and mass the effect of the eccentricity is the following: i) all frequencies increase with the eccentricity, but with different rate, ii) double frequencies of non-axisymmetric vibrations of a circular plate split into two, the lower frequency corresponds to the mode stretched along the long semi-axis, the effect on the frequencies for small values of the axis ratio (up to 1:2) is linear with the high accuracy, iii) lower frequencies go up with the eccentricity faster, as a result for some values of the eccentricity the mode order changes.

Frequencies and modes were also found by finite element method using the package ANSYS 18.1. The results were compared with those obtained by other authors who used Rayleigh- Ritz and other numerical methods.

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# TWO-WAY GLOBAL-LOCAL APPROACH FOR PROGRESIVE FAILURE ANALYSIS APPLIED TO A LARGE STIFFENED COMPOSITE PANEL WITH INTRALAMINAR DAMAGE AND SKIN-STRINGER DEBONDING

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This study is dedicated to the progressive failure analysis of large composite laminate stiffened panels, which are widely used in aircraft design. The progressive failure analysis is carried out by means of a two-way global-local approach developed earlier [1]. This method is an efficient and reliable technique enabling the prediction of onset and growth of matrix and fiber failure, as well as separation between the skin and the stringer.

According to the proposed approach, at the global level a linear elastic coarse model with shell elements is emplyed to detect the probable areas of damage. Afterwards, local models are generated using a fine mesh with solid elements. Kinematic constraints are used as boundary conditions corresponding to prescribed displacements for the transfer from the global to the local model. The damage evolution is simulated by means of a material degradation model and cohesive elements applied at the local level. To ensure a full information exchange between the two levels, a transfer of the reduced material properties from the local to the global level is carried out. As the relative element sizes of global and local models are different, a special homogenization procedure is implemented. The global-local steps are executed until the final failure takes place. This method was previously applied to one-stringer panels [2], and a five-stringer panel, the latter considering only intralaminar damage.

In the current work, the global-local approach is applied for on a realistic large panel under compression with several stringers and compared with available experimental results to examine various damage types such as intralaminar damage and skin-stringer separation. It is shown that the proposed global-local method not only significantly reduces computational costs, but also enables the accurate prediction of damage initiation and progression until final failure.

[1] S. Huehne, J. Reinoso, E. Jansen, and R. Rolfes, "A two-way loose coupling procedure for investigating the buckling and damage behaviour of stiffened composite panels," *Compos. Struct.*, no. 136, pp. 513–525, 2016.

[2] M. Akterskaia, E. Jansen, and R. Rolfes, "Progressive Failure Analysis of Stiffened Composite Panels Using a Two-Way Loose Coupling Approach Including Intralaminar Failure and Debonding," in *2018 AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, AIAA and Astronautics, 2018.

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# A NOVEL TRIANGULAR SHELL ELEMENT FOR PIEZOELECTRIC SMART STRUCTURES

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The last two decades have seen rapidly growing interest followed by massive development in the field of active/adaptive/smart structures. The substantial research attention and work were attracted by enormous potential benefits smart structures offer over passive ones. The essence of the *smart structure* concept consists in transforming a conventional, passive system into an active one by adding/embedding active elements, i.e. sensors and actuators, which are coupled by means of a controller to produce teamwork. This enables active control over structural behaviour, which may be aimed at vibration suppression, shape control, radiated noise reduction, etc.

Thin-walled structures, particularly those made of modern light-weight materials, are of most practical interest in a variety of applications involving automotive, aerospace, aeronautical, to name but a few. Due to the stability issues and excessive vibrations those structures are intrinsically prone to, they are a viable candidate for implementation of the smart structure concept. Though various devices can be applied as sensors and actuators, those with high-integration ability into conventional thin-walled structures are of particular interest. This further implies use of multi-functional materials characterized by pronounced coupled-field effects, such as the piezoelectric effect. The most common form of active elements for this purpose is thin piezoelectric patch/layer.

Numerical tools for modelling and simulation of smart structures open up new frontiers of their development. They have to respond to various challenges imposed on them. Regarding modelling of thin-walled structures, a shell finite element should offer high meshing ability and numerical efficiency combined with accuracy. The authors propose a novel triangular shell element for simulation of static and dynamic behaviour of piezoelectric thin-walled structures. As shell elements are notorious for locking effects, the developed element represents a novel combination of existing solutions for their treatment. The discrete shear gap (DSG) approach is implemented for treatment of shear locking. The membrane behaviour is resolved by combining the basic - constant stress - formulation and the assumed natural deviatoric strains (ANDES) formulation. Furthermore, the element formulation assumes that pizeoeletric patches are polarized in the thickness direction and operate using the so-called $e_{31}$-effect thus coupling the thickness oriented electric field with the in-plane strains. Examples are given to demonstrate element properties and applicability for thin-walled smart structures.

# Microgravity-induced structural changes in ISS-mice reduce femoral stiffness by one third: results from a micro-CT-image-based Bernoulli-Sapountzakis beam theory, validated by 3D FEM

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Exposition of mice to microgravity conditions as experienced in the International Space Station (ISS) induces significant microstructural changes in their skeleton, as evidenced in a pioneering microCT studies of femora of microgravity-exposed mice, as well as of counterparts from animals living under normal gravitational conditions [1]. We here study the mechanical implications of these structural changes. In order to translate the micro-CT-defined structural information into the load bearing behavior of the skeletal structure, we develop a new advanced beam theory for long bones. Therefore, classical Bernoulli bending deformation states are combined with three types of warping functions allowing for realistic shear deformation modes of the beam which undergoes not only bending, but also restrained torsion [2]. The principle of virtual power allows for the identification of relevant stress resultants in terms of normal and shear forces, as well as bending and torsional moments, and of equilibirum conditions to be fulfilled by these resultants. Complementing these relations by equilibrium and compatibility relations at the cross sectional level yields integral equations for the warping functions, which are solved by 2D Finite Element Method, on domains which are directly derived from the microCT information. Corresponding results are validated through standard 3D Finite Elements, which, however, require much more computational cost, by a typical factor of 100. The mechanical implications of microgravity may be quantified in terms of the strain energy related to a typical load case: ISS-exposed mice femora exhibit a stiffness reduced by about 30%.

**References**:

[1] Tavella S, Ruggiu A, Giuliani A, Brun F, Canciani B, Manescu A, et al. (2012) Bone Turnover in Wild Type and Pleiotrophin-Transgenic Mice Housed for Three Months in the International Space Station (ISS). PLoS ONE 7(3): e33179. https://doi.org/10.1371/journal.pone.0033179
[2] Sapountzakis E (2013) Bars under Torsional Loading: A Generalized Beam Theory Approach. ISRN Civil Engineering, Article ID 916581, 39 pages. https://www.hindawi.com/journals/isrn/2013/916581/

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# Actuator Placement in Adaptive Structures – Redundancy Distribution vs. Disturbance Compensability

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In order to meet the requirements of tomorrow's world, engineers and architects must design extremely efficient structures. Making engineering structures adaptive is a promising approach to increase the load carrying efficiency of structures noticeably. The aim is to reduce the required mass of engineering structures by active and adaptive manipulation of the static and dynamic structural response (e.g. forces, deformations and vibrations).

According to Ströbel [1] the distribution of the static indeterminacy in the system can be described by the redundancy contribution of each element of a truss. Also for the integrative design of efficient adaptive structures in civil engineering the redundancy distribution can be applied. The redundancy matrix, containing the redundancy contributions of all elements, is directly related to the space of adaptability. It can also be used to find favourable positions for the actuators, assessing controllability on the basis of insight into structural behavior, without application of complex and time consuming optimization algorithms.

The redundancy matrix as a concept from structural engineering is closely related to ideas for actuator placement from control engineering. The concept of steady-state disturbance compensability [2] is introduced and a close relationship to the concepts of redundancy and statical indeterminacy in structural mechanics of truss structures is revealed, leading to a new method for actuator placement in linear structural systems under stationary loads.

The aim of this work is to contribute to a holistic understanding of actuator placement for compensation of steady-state disturbances in adaptive structures, taking control as well as structural engineering concepts into account. This includes a better insight into the load bearing behaviour of adaptive systems and to characterize them.

# References

[1] D. Ströbel, *Die Anwendung der Ausgleichungsrechnung auf elastomechanische Systeme*. Ph.D. dissertation. Institut für Anwendungen der Geodäsie im Bauwesen, Universität Stuttgart, 1995.

[2] Julia Laura Wagner, Jan Gade, Michael Heidingsfeld, Florian Geiger, Malte von Scheven, Michael Böhm, Manfred Bischoff and Oliver Sawodny, *On Steady-State Disturbance Compensability for Actuator Placement in Adaptive Structures*. at - Automatisierungstechnik, submitted, 2018.

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# MULTI OBJECTIVE OPTIMIZATION OF LATTICE STRUCTURE USING 3D BEAM AND SHELL FE ANALYSIS.

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Selective laser melting (SLM) technology enables layer-by-layer production of complex metal parts based on a three-dimensional model, which reduces the manufacturing constraint or limitations related to design complexity. This technology enable fabrication of complex lattice structures, whose features can span several applications [1]. This is due to the excellent mechanical properties: ultra-lightweight, high specific strength, high specific rigidity. These structures consist of a large number of trusses arranged in spatial patterns with selected unit cell design. The cells' optimum arrangement has been the focus of numerous research studies. Very early work in the field of structural optimization became known as Michell structures. However, this approach is not practical because they need an infinity of bars [2]
Optimization technique is used in many researcher, to improve the structural characteristic. Topology optimization can therefore allow greater design freedom than parametric optimization. Various topology optimization approaches have been developed over recent years [1,3,4]. Therefore, in order to avoid the height computational time, often the topological optimization are limited to a single mechanical element propriety using the homogenization technique [5,6]. Other researcher have used parallel computing techniques to resolve two-scale model, i.e, micro problem to characterizing the material microstructure using finite element analysis, and macro model using the homogenization results for the topological optimization[7]. Parametric optimization can also be used to parametrically control the lattice geometry and diameters in response to external load cases. However, the solid Finite element analysis become time consuming. Moreover, the lattice arrangement become difficult to integrate.

In this paper, to overcome the time consuming of solid structure, beam and shell finite element analysis is carried out using Comsol multiphysics software to analyze the scooter structure in response to external load. The model combines 3D Euler beam elements for the lattice structure and shell elements representing the external skin (Figure 1). The first objective of this work is to study, using Taguchi the effect of the geometrical parameters and diameters of 3D Hexa-Truss structure, on various mechanical properties such as high strength, rigidity and weight. The second objective is to optimize using multi objective Genetic algorithm. The optimization problem is formulated in order to minimize two objective function: the global structural weight and the maximal value of Von-Mises stress in the beam. The optimal structure give a decrease of 54% of the stresses compared to the permissible stress value and decrease of 75% of the weight compared to the initial structure.

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# NON-LINEAR MODELING OF PIEZOELECTRIC MATERIALS: A PHENOMENOLOGICAL APPROACH TO LARGE DEFORMATION AND HYSTERESIS

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By the term smart materials, we refer to materials that respond to external stimuli, which enables the usage as sensors or actuators. In engineering applications, piezoelectric materials represent a prominent example, where the direct and converse piezoelectric effects are used for both sensing and actuation. The response of piezoelectric materials is related to its state of polarization and the presence of an external electric field. Traditionally, the remanent polarization is assumed to be constant during operation of a device. The necessity for both physically and geometrically non-linear models, however, has increased in view of the technological advances in embedding piezoelectric materials, for instance, and pushing the operational limits of sensors and actuators, an accurate understanding of the poling process and the evolution of the material's state of polarization, i.e., the their domain state, is required. In piezoelectric materials, the electro-mechanical coupling in piezoelectric materials manifests in ferroelectric and ferroelastic hystereses, which are related to both reversible (e.g., domain-wall motion) and irreversible (i.e., domain switching) physical processes. Focusing on the latter, we transfer phenomenological models for domain switching [1] to the geometrically non-linear regime using the non-linear formulation for reversible piezoelasticity [2] as a basis. For this purpose, we follow related concepts of geometrically non-linear elasto-plasticity [3], where the concept of a Lee-type multiplicative decomposition of the deformation gradient plays a key role. Therefore, an additional deformation path that describes the evolution of the poled state from the unpoled referential configuration is introduced. Within the phenomenological approach, micro-mechanically inspired internal variables related to the orientation of unit-cells [1] are introduced. Driving forces and evolution equations are derived within a thermodynamical framework.

[1] M Kamlah. Ferroelectric and ferroelastic piezoceramics – modeling of electromechanical hysteresis phenomena. *Continuum Mechanics and Thermodynamics*, 13(4):219–268, 2001.

[2] A Humer, E Staudigl, and M Krommer. Nonlinear electro-elasticity for piezoelectric materials and structures using a multiplicative decomposition of the deformation gradient. In A Güemes, A Benjeddou, J Rodellar, and J Leng, editors, *Proc. 8th ECCOMAS SMART 2017*, pages 1316–1327, 2017.

[3] V A Lubarda. Constitutive theories based on the multiplicative decomposition of deformation gradient: Thermoelasticity, elastoplasticity, and biomechanics. *Applied Mechanics Reviews*, 57(2):95–108, 2004.

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# PREDICTION OF DEBONDING ONSET IN FIBER-REINFORCED POLYMER COMPOSITES VIA A GLOBAL-LOCAL APPROACH

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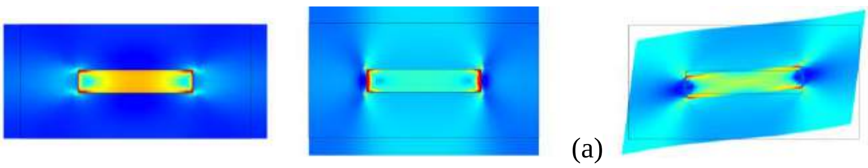
In the last decades, the study of the mechanical properties of micro- and nano-composites has become increasingly popular in both industry and academia due to their enhanced mechanical and fracture properties. Generally speaking, fiber breakage, interface debonding and matrix cracking are main phenomena that lead to failure of composite materials, whereas in polymer nano-composites, due to the extremely high tensile strength of the reinforcement phase, fiber breakage is unlikely and accordingly, interfacial debonding and matrix cracking can be considered the most frequent failure modes. The purpose of this work is to perform a numerical investigation of interfacial debonding onset in both micro- and nano-composites to better evaluate its influence on their overall mechanical properties. To this end, assuming that the reinforcement at the local scale is made of a periodic arrangement of equally sized and oriented short fibers, a novel global-local approach inspired by micromechanics is proposed to numerically derive the homogenized strength properties of such composites. By using cohesive laws properly derived from atomistic models, this approach can be directly specialized to the failure analysis of fiber-reinforced polymer nano-composites.



(a) (b)

Figure 1 Deformed configurations of a periodic short-fiber polymer composite subjected to (a) two uniaxial, and (b) a shear macro-strain modes.

Specifically, several local analyses performed on a unit cell playing the role of Representative Volume Element (RVE) provide the envelope of the elastic limit macrostrains for the composite, here called First Failure Surface (FFS), corresponding to the initiation of the interfacial debonding. Such a locus, which is defined in the macrostrain space, is derived by interpolating the failure points obtained considering a finite subset of macrostrain paths (see Figure 1) and can be used as the main ingredient of a novel multiscale model approach with adaptive capabilities for the accurate failure analysis of composites. This model will be able to reduce the typically high computational cost exhibited by fully microscopic numerical analyses, exploiting an advanced refinement criterion based on the obtained FFS.

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# MuPIF – A PLATFORM FOR INTEGRATING MATERIAL AND PROCESS MODELS INTO A WORKFLOW

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Linking and coupling material and process models into a simulation workflow requires communication between several codes, feed them with input data, steering and orchestrating their runs, checking for possible errors and extract required outputs. This can be facilitated by integration platform MuPIF [1,2].

MuPIF is a distributed, object-oriented framework written in Python 3.2. The top level abstract classes are introduced for models (simulation tools) and generic data types. They define abstract interfaces allowing to manipulate and steer derived classes (representing individual models and specific data representations) using the same generic interface. One of the key features of the MuPIF platform is the definition of abstract interfaces for models as well as for high level data types (spatial fields, microstructures, for example). This allows to achieve true plug&play architecture, where individual application can be plugged into existing workflows and be manipulated using the same interface. As the same concept is applied for high level data, the platform natively support different data formats, storage schemes and even data repositories. Such approach is highly general to accommodate various models in Composelector project [3].

We demonstrate MuPIF capabilities on a linked CFD-thermomechanical task, consisting of a steel beam placed into a furnace with gas burners, see the geometry in  Figure. The furnace is of dimensions 3.0 m x 4.0 m and 2.2 m height and heated by 8 natural gas burners. The simply-supported beam is made from steel I profile 3.8 m long, placed just under the furnace ceiling.

Two codes are used for the a linked simulation; Fire Dynamics Simulator software (FDS), developed at NIST [4] and OOFEM thermomechanical code developed at Czech Technical University in Prague [5].  Figure shows their interaction using MODA diagram coined by EMMC. MuPIF interconnects and orchestrates all the continuum models.

The results were computed end exported to VTU files.  Figure left shows a cross-section through the middle of the furnace. We can see the two FDS meshes, one coarse on the whole furnace and one finer around the beam, which is necessary for the interpolation close to the ceiling.  Figure right provides detailed normal stress $\sigma_x$ at time t=576 s.

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# ELECTROSPUN MATERIALS FOR SOUNDPROOFING

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New light (density=63 $Kg/m^3$) soundproofing materials were obtained through electrospinning of alcoholic suspensions of high molecular weight (1300 KDa) polyvinylpyrrolidone (PVP). The sound absorbers were obtained in the form of blankets of thin disks of 10 cm diameter. For a given set of disks (from a minimum of 6) the sound absorption coefficient $\alpha_a$ changes, in the frequency range 200-1600Hz, following a bell-like curve with a maximum (close to 1.0) that shifts to lower frequencies the higher the piled disks number (and mass), so as shown in Fig.1.

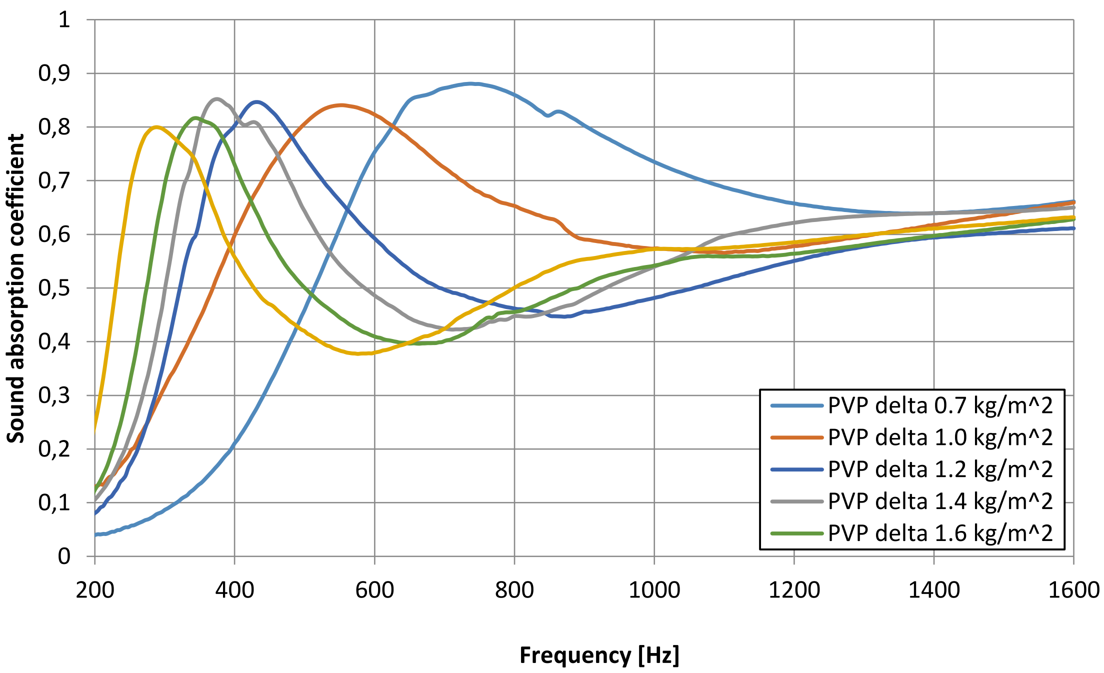


Figure 1 Sound absorption coefficient vs frequency of PVP blankets of different mass.

The experimental results suggest that sound energy dissipation occurs primarily because of resonance of the sound wave with the natural frequency of vibration of the disks pile (acting as a membrane).

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# Experimental and numerical investigation of Free vibration analysis and control of composite plates with and without delamination

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Experimental and Numerical investigation of vibration responses of laminated composites plates with and without delamination is presented. In the present analysis, glass fibers and carbon fibers composite plates are taken into consideration. Macro-fiber composite (MFC) patches were used as sensor/actuator to suppress the unwanted vibration responses. MFC sensor and/or actuator are installed at the top and the bottom of the laminated plate. An experimental set up is developed for vibration analysis and control. The main part of the set-up is the dSPACE DS 1104 controller board in Autodesk software conjunction with MATLAB. Modal exciter is used to give the initial excitation to the plates. The standard specimens of laminated and delaminated plates with a different size of delamination are taken for the experimental analysis. A finite element model for both delaminated and without delamination composite plates is also developed. The effects of delamination size (with different sizes, location, and positions) are studied numerically. The numerical and experimental data is compared with the data available in the published literature.
The specialty of the laminated composite materials i.e., stiffness to weight ratio is high due to which they are widely used now a day with very advance application in automobiles, aircrafts and marine industries. But the performance of the plates deviates from the desired output when delamination occurred in it, in the form of vibration, so to overcome this unwanted shiver their control is necessary. Here an attempt is made to control the vibration by applying a voltage to the plate through piezoelectric materials experimentally.

# Aircraft interior noise prediction through Statistical Energy Analysis method

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Aircraft fuselage structures are characterized by their lightweight design. The reduction of the mass of a structure is an important issue in the engineering field since it leads to reduced emissions and operating costs. On the other hand weight saving leads to an increase of vibration and noise transmission causing discomfort in the passengers. For this reason in the last years, the dynamic design of lightweight structures has received more emphasis such that it is done simultaneously with design process of the aircraft.

In the dynamic behaviour of a structure, according to wavelength, there are two basic approaches: deterministic and stochastic. In the low frequency range the behaviour of a structure is deterministic and the basic tools applied for the analysis of vibration problems is finite element analysis on the numerical side and experimental modal analysis on the testing side. Model validation of finite element models for the low frequency range is mainly based on the correlation of eigenfrequencies and mode shapes from experiment and simulation.

In the high frequency range, instead, the behaviour of a structure is stochastic which means that the dynamic response change strongly in case of small changes and uncertainty and statistics of system have to be taken in consideration. In the high frequency range, Statistical energy analysis (SEA) is widely used for the determination of vibration levels of the subsystems of structure. For correlation purposes in the higher frequency range, sound pressure levels and vibration levels are measured on pre-defined positions and are compared with simulated levels.

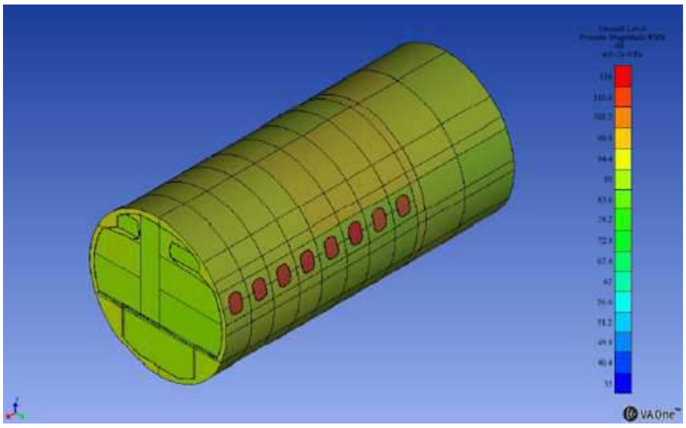

Figure 1: Overall Sound Pressure Level (OASPL) of a cabin fuselage section.

# Deep Cryogenic Treatment effects on wear properties of AA6061 Metal Matrix Composites

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The application of Deep Cryogenic Treatment (DCT) has been widely tested on steels, with particular focus on machine tools for increasing hardness and resistance to wear. Currently, the focus is moving towards application of DCT on light alloys and Metal Matrix Composites (MMC) in order to investigate potential benefits with respect to the base material properties.

In this study, the wear properties of Aluminium alloy (AA6061) matrix composites subjected to DCT are experimentally investigated and compared to the conventionally treated material. AA6061 properties include its structural strength and toughness, its good surface finish, its good corrosion resistance to atmosphere and sea water, its machinability, and its ability to be easily welded and joined. It is one of the most used light alloys, including application for vehicle body panels and chassis, driveshafts, brake components, fasteners and fitting, sheet metal work.

Specimens based on AA6061 matrix reinforced with different combination of commercially available fly ash, Silicon carbide particles (SCP), whiskers (SC9M) and fibres (SCF7M), Molybdenum disulphide (MOS2) and Tungsten disulphide (WS2) were manufactured using stir casting process.

Reciprocating and continuous pin-on-disk tests (Fig. 1) were performed at different levels of load and speed according to ASTM G-99 standard. Wear and friction coefficients were evaluated and wear tracks were compared through optical microscopy.

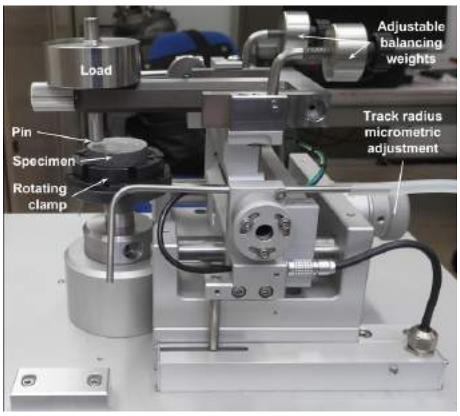


Figure 1: Example of pin-on-disk test.

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# Three-dimensional Stress Distribution in Tow-Steered Composite Structures

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The application of laminated composite structures has significantly increased in various engineering disciplines over the recent decades. This acceptance is mainly due to their high specific strength and stiffness, good fatigue resistance and damage tolerance characteristics. Composites also allow designers to tailor the properties through their thickness by varying fibre orientation of each ply and optimizing the stacking sequence for the structure performance. However, current design and manufacturing methods put limits to the potential structural efficiency that composite structures are capable of. Therefore, studies on Variable Angle Tow (VAT) composites are gaining increasing attention. The concept of curvilinearly placing the fibre (tow) within a lamina adds a further dimension to the capability for tailoring and can significantly improve the performance of a structure without increasing its weight. Furthermore, recent advancements in composite manufacturing technology have facilitated the production of laminates with VAT, providing an enlarged design space. With an increase in availability and use of curved fibre laminates, there is a need to develop accurate, yet computationally efficient, modelling techniques. The present work focuses on the three-dimensional (3D) stress analysis of tow-steered composite structures using a displacement-based numerical approach based on 1D Unified Formulation. Our study highlights the advantages of using the proposed model over 3D finite elements and other mixed formulations available in the literature. 3D stress distributions are examined for laminates with various linear and non-linear fibre angle variations.

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# Advanced models for the accurate evaluation of interlaminar stresses in composites with applications to free-edge effects and delamination

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The present study presents a novel methodology for the accurate evaluation of interlaminar stresses in generic composite laminates which is based in the use of refined 1D theories with non-local assumptions over the cross-section. The numerical simulation of the interlaminar stresses in laminated structures is a topic of major interest in the composite community. In many structural applications, the high stress concentrations that arise at the free edges of the interfaces provoke the appearance of delamination zones, which reduce the performance of the composite component and give rise to further failure modes. In this matter, analytical and semi-analytical models have proven to be a useful tool, although they are usually limited to certain geometries and boundary conditions. On the other hand, the use of 3D finite element models can extend this study to general problems, but they require very refined discretizations to capture the localized effects that arise at the interfaces between layers, restricting in great manner its use. To solve this issue, in this work the Carrera's Unified Formulation is employed to reduce the 3D problem to a 1D analysis in which non-local higher-order polynomials are employed to expand the variables over the cross-section plane. Standard shape functions are used to interpolate the variables along the beam axis, whereas only-displacement assumptions and mixed displacement-stress assumptions based on the RMVT are considered over the section of the laminate in a layer-wise sense. The use of locally-defined expansion domains allows the user to refine the model in the zones of interest, i.e. the free-edges, while the mesh of the longitudinal axis remains coarse. In this manner, the computational size of the model can be reduced by orders of magnitude in comparison to solid models, and moreover, different boundary conditions and geometries can be evaluated. Results of tensile, bending and torsion cases in composite laminates are presented, as well as bonded joints tests.

# VIBRATION OF A HONEYCOMB SANDWICH STRUCTURE WITH AN ON FACE BONDED MACRO FIBER COMPOSITE

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Honeycomb sandwiches are popular materials for alleviating the weight, noise or vibration of many industrial structures, such as in aeronautics, building constructions or goods packaging. Their cores can be metallic (mostly aluminum) or in paper while their faces can be metallic, composite (with carbon or glass fibers) or in paper. In order to functionalize resulting structures, smart materials can be surface-bonded to them in order to be used as sensors, actuators are transduces for vibration, noise or shape control and health monitoring or transduction (energy conversion) applications, rendering smart the host structures.

This work presents *testing* and *finite element* (FE) simulation challenges of a *vibrating* sandwich coupon (plate), made of an *aluminum* honeycomb core and Glass Fiber Reinforced Polymer (GFRP) *composite* faces, on which is bonded a *piezoelectric* Macro Fiber Composite (MFC) large patch (see Figure 1). The testing challenges come from the light weight of the coupon, while the numerical ones come from the fact that the geometric and materials data of both the host honeycomb sandwich and MFC patch are unknown.

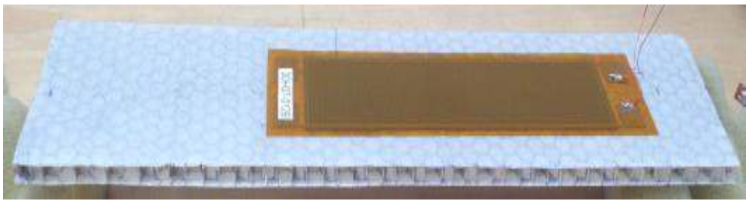

Figure 1 Honeycomb sandwich plate with an on face bonded MFC large patch.

Therefore, *reverse* engineering was first conducted in order to get the geometric details of the honeycomb core, faces and the glues in between. Then, the elastic modulus was obtained from model-test *correlation* under *free* boundary conditions. Next, the material properties of the MFC wre obtained through a FE *homogenization* technique. A *meshing tool* and its *GUI* were developed within Matlab® that generates automatically an *APDL script* useable within ANSYS® commercial FE code. The honeycomb core and composite faces were meshed using 4-node shell elastic elements, while the MFC patch was meshed using 8-node *coupled* solid ones. It is worthy to mention that each wall of the honeycomb core cell was considered as a *single* FE, leading to a *refined* 2D (for the sandwich)/3D (for the MFC patch) FE model.

Comparison of the *bare* and e *smart* sandwich *short-circuit* and *open-circuit*, with electrodes *equipotential* constraints, frequencies showed good correlations.

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# Optimal location of piezoelectric patches for noise reduction in sandwich panels

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Noise reduction is a fundamental issue for the competitiveness in the transportation industry. Structures should be optimized for cost, weight, vibration and noise attenuation, subject to technological, failure and stress constraints. The generalized introduction of lightweight composites in the automotive and aerospace industries, while leading to significant weight reductions and associated fuel savings, pose a serious problem of low acoustic performance of these lightweight composites when subjected to mechanical or acoustic excitations. Passive damping technologies are nowadays frequently used to control sound and vibration levels through the use of viscoelastic materials, while active devices such as surface bonded piezoelectric patches can also be effectively used to control these undesired sound and vibration levels in lightweight composite structures. Sandwich composite panels may represent an optimized solution for both sound radiation and structural vibration for most frequency ranges. Viscoelastic materials are an efficient way of reducing structural vibrations and providing noise attenuation, which allied to active elements may lead to broader control capabilities regarding acoustic emissions.

This paper addresses the issue of noise reduction in laminated sandwich plates using both passive and active elements. A finite element implementation of a laminated sandwich plate element with viscoelastic core and surface bonded piezoelectric patches is used to obtain the frequency response of the panels. The sound transmission characteristics of the panels are evaluated by computing their radiated sound power and radiation efficiency, using the Rayleigh integral method. The optimal location of the surface co-located pairs of piezoelectric patches is then obtained to minimize both weight and noise radiation. A recent methodology of optimization, based on direct search techniques, was used: Direct MultiSearch (DMS) optimization. This methodology does not use derivatives and does not aggregate any of the problem objective functions. Trade-off Pareto optimal fronts and the respective optimal active patch configurations are obtained and the results will presented, analyzed and discussed.

# SLM-EBM PROCESSES OPTIMIZATON FOR METAL LATTICE STRUCTURES FABRICATION

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The diffusion of lattice structures is motivated by the availability of recent additive manufacturing (AM) technologies and by specific needing of lightweight components in industry [1, 2]. However, traditional setups of selective laser melting (SLM) and electron beam melting (EBM) process are not suitable for lattices and dedicated process optimization is needed. Uniformity of lattice texture and dimensions close to the nominal design are the main challenges, together with fabrication of long and thin struts. Additionally, traditional temporary supports used in AM are not applicable to lattices. Specific lattice design must be used, able to make every cell self-sustained [3, 4].
Cubic cells lattice samples with 20x20mm$^2$ base and 12 cells layers (Fig. 1a) are used to calibrate the fabrication process on the EOS 290M and Archam Q10 machines. Ti6Al4V powder with 45µm granulometry is used. The design of experiment (DOE) method is applied to determine the volumetric energy density (VED) applicable to the struts downskin in order to achieve the desired dimensions and roughness. The material density is also measured with values ranging between 99.14 and 99.97%. Optical micrographies (Fig. 1b) are used to evaluate dimensional properties of samples and provide statistical distribution of results (Fig. 1c).

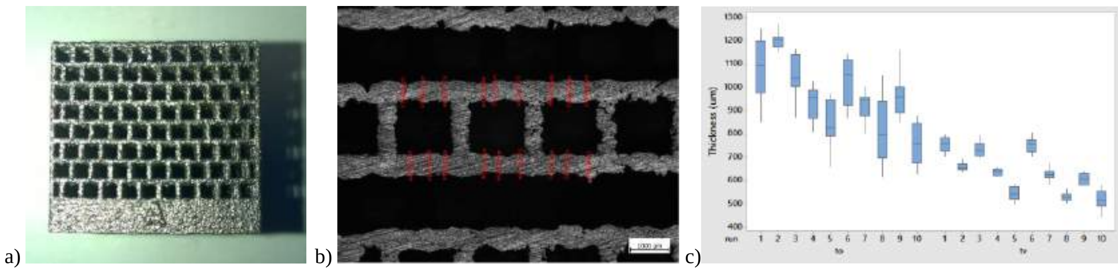

Figure 1. Lattice sample (a), optical micrography (b) and struts thickness evaluation (c).

[1] Sing S.L. et al. Selective laser melting of lattice structures: a statistical approach to manufacturability and mechanical behavior, Robotics and Computer-Integrated Manufacturing, 49, 170-180, 2018.
[2] Feng Q. et al. Quasi-static analysis of mechanical properties of Ti6Al4V lattice structures manufactured using selective laser melting, Int. J. of Advanced Manuf. Tech., 94, 2301-2313, 2018.
[3] De Pasquale G. et al. Cellular structures from additive processes: design, homogenization and experimental validation. Procedia Structural Integrity Procedia, 8, 75-82, 2018.
[4] De Pasquale G. et al. Experimental characterization of EBM and SLM cubic lattice structures for lightweight applications. Sub. to Experimental Mechanics, 2017.

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# Contact modeling within displacement-based refined one-dimensional beam models

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The paper presents a novel contact formulation for higher-order beam elements developed within the scheme of the Carrera Unified Formulation (CUF) [1]. One-dimensional CUF models assume variable kinematic descriptions over the cross-section of the beam without any ad-hoc assumptions. CUF makes use of fundamental nuclei to express the governing equations independently of the order of the structural theory. In this work, Lagrange-type polynomials are used to interpolate the displacement field over the cross-section leading to a purely displacement-based refined one-dimensional model. An efficient global contact algorithm scheme utilizes the accurate displacement field to precisely enforce the contact constraints. The contact fundamental nucleus is formulated through the consistent linearization of contact contribution, thus allowing their application within implicit time integration scheme. Typical limitations associated with beam-to-beam contact formulations [2] are easily eradicated through the unified formulation. The proposed work extends the advanced capabilities of CUF framework to approximate accurate 3D fields at a reduced computational overhead for solving contact problems. A numerical simulation campaign, including patch tests and benchmark tests, is undertaken to verify the accuracy and efficiency of the proposed contact modeling within the CUF framework.

## References

[1] Carrera E., Cinefra M., Petrolo M. and Zappino E., *Finite Element Analysis of Structures through Unified Formulation*, John Wiley and Sons, Ltd, 2014.

[2] P. Wriggers and G. Zavarise, *On contact between 3-dimensional beams undergoing large deflections*, Communications in Numerical Methods in Engineering 13(6):429 - 438 (1997) .

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# A component-wise formulation for virtual testing of composites

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This research work presents a computationally efficient and accurate platform for virtual testing of composites. The present model is based on a class of refined one-dimensional (1D) theories referred to as the Carrera Unified Formulation (CUF), a generalized hierarchical formulation that yields refined structural theories through a variable kinematic description [1]. 1D CUF models can provide accurate 3D-like stress fields at a reduced computational cost, e.g., approximately one to two orders of magnitude of degrees of freedom less as compared to standard 3D brick elements. The virtual testing platform consists of a variety of computational tools such as failure index evaluations using component-wise modeling approaches (CUF-CW), CUF-CW micromechanics, $CUF^2$ multiscale framework, and interface modeling. The Component-Wise approach (CW) is utilized to represent various components of the RVE in the CUF-CW micromechanics module [2]. The crack band theory is implemented to capture the damage propagation within the constituents of composite materials and the pre-peak nonlinearity within the matrix constituents is modeled using the $J_2$ von-Mises theory. A novel multiscale framework, $CUF^2$, is developed for nonlinear analysis of fiber-reinforced composites. The two-scale framework consists of a macro-scale model to describe the structural level components, e.g, open-hole specimens, coupons, using CUF-LW models and a sub-scale micro-structural model encompassed with a representative volume element (RVE). The two scales are interfaced through the exchange of strain, stress and stiffness tensors at every integration point in the macro-scale model. Explicit finite element computations at lower scale are efficiently handled by the CUF-CW micromechanics tool. A novel higher-order interface modeling approach is utilized to model delamination. The tools mentioned above are employed to obtain accurate material response across various scales of composite modeling. The efficiency of the proposed computational platform is assessed via comparison against the traditional approaches found in the literature.

# References

[1] Carrera E., Cinefra M., Petrolo M. and Zappino E., *Finite Element Analysis of Structures through Unified Formulation*, John Wiley and Sons, Ltd, 2014.

[2] Kaleel I., Petrolo M., Waas A.M., Carrera E., ”Micromechanical Progressive Failure Analysis of Fiber-Reinforced Composite Using Refined Beam Models”, Journal of Applied Mechanics (2018), 85.

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# Micromechanics-based multiscale modeling for nonlinear analysis of fiber-reinforced composites using DIGIMAT

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The research work presents numerical investigations on nonlinear mechanics, damage and failure behavior for a class of composite materials and structures through micromechanics-based multiscale analysis. A computational framework based on DIGIMAT and MSC NASTRAN is utilized to model the problem in hand [1]. At the microscale, various constituents of the microstructure (fiber, inclusions, cavities, etc.) are modeled as a representative volume element (RVE). Two approaches are utilized to address the virtual material characterization and scale transition, namely, the direct finite element analysis (FEA) and mean field homogenization technique (MFH). The former method provides a detailed and accurate description of the micro field, but may lead to very high computational overheads from a macroscopic structural perspective. The latter is based on a semi-analytical method (Self-consistent, Mori-Tanaka and Double Inclusion) accompanied by great computational efficiency with lower details on local distributions due to volume averaging. Nonlinearity within the microstructure constituents is modeled through a class of nonlinear models such as the elasto-plastic damage model (Lemaitre-Chaboche model [2]). The study shall address how the aforementioned approaches prove efficient and accurate in the prediction of composite materials and structures response across different scales, from micro (investigating the effect of defects, local distributions, singularities) to macro (with the structural analysis of a composite panel). Numerical predictions are validated against existing numerical and experimental results from literature.

# References

[1] MSC Software Company. Digimat User's Manual. E-xtream Engineering, 2018.

[2] J. Lemaitre and J.-L. Chaboche. Mechanics of solid materials. Cambridge University Press, 1990.

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# GLOBAL-LOCAL TECHNIQUES FOR MACROSCALE ANALYSIS AND KEY PERFORMANCE INDICATOR EVALUATION OF COMPOSITE STRUCTURES

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The current work deals with the stress analysis of complex composite structures using a combination of refined beam models and global-local techniques. The refined beam models are obtained within the framework of the Carrera Unified Formulation (CUF), where expansion functions are used across the cross-section to enrich the kinematics of the finite elements, resulting in 3D-like accuracy of the solution at a fraction of the computational cost associated with a full 3D FEA [1]. Global-local techniques are used to focus the analysis on a specific region of the structure where highly accurate stress fields are required, for instance in the neighbourhood of a stress concentrator. The extent of the local region is determined using failure indices which are calculated based on criteria such as LaRC05.

In the current work, the global structure is modelled in a commercial software (ABAQUS) and the local analysis is performed in CUF, thus demonstrating the capability of interfacing the academic and commercial codes. The displacements obtained from the global analysis are used as boundary conditions for the local analysis. Such a global-local methodology can be of advantage while performing a refined analysis of an existing model, since remeshing of a complex structure can be avoided. The results obtained using the global-local technique are in good agreement with reference 3D FEM solutions, as can be seen in Figure 1 for the case of a plate with a hole, with a significant reduction in the number of degrees of freedom.

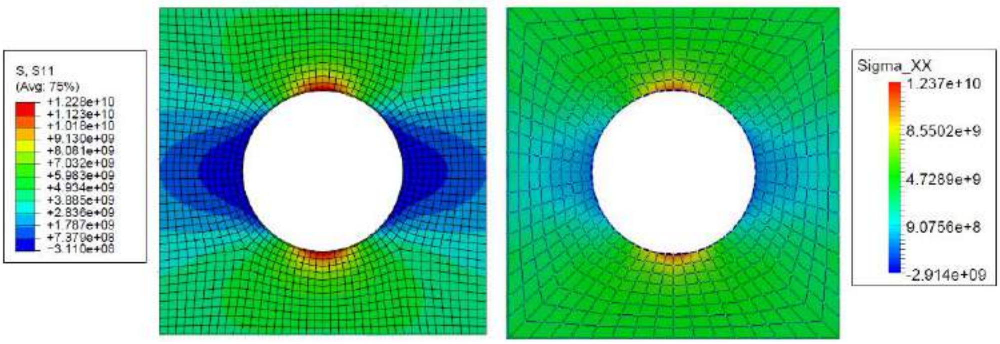


*Figure 1: Contour plot of the axial stress near a hole (left) 3D FEA, and (right) analysis of the local region in CUF*

## References

[1] Carrera E, Cinefra M, Petrolo M, and Zappino E, 2014, Finite Element Analysis of Structures through Unified Formulation, John Wiley & Sons

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# Hierarchical Legendre expansion for the dynamic response and wave propagation of metallic and composite beams

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An efficient tool for the analysis of the dynamic response and wave propagation of composite structures is presented. The Carrera's unified formulation (CUF) is used to generate higher-order beam theories that are able to deal with complex dynamic behaviors with a solid-like accuracy and reduced computational efforts. For this purpose, the Hierarchical Legendre Expansion (HLE) is employed to expand the displacement unknowns over the cross-section of the beam by means of locally defined domains which can represent arbitrary geometries of the structure. In this manner, any deformation state can be represented, e.g. shear and torsional warping, and the accuracy of the model is tuned by the polynomial order of the Legendre functions, which remains as a user-defined input of the analysis. The governing equations are obtained both in weak and strong form. For the former, the Finite Element Method (FEM) is recalled to discretize the longitudinal axis by means of 1D beam elements and, subsequently, the hp-convergence is studied. On the other hand, locally supported Radial Basis Functions (RBF) are employed to generate a class of meshless models based on Wendland's $C^6$ functions. The latter presents some interesting features for the dynamic analysis of beam-like structures, including high-fidelity of the solutions and computational advantages. The results from these two approaches are assessed and compared, and the coupling FEM-RBF is investigated.

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# PERIDYNAMIC MODELLING OF REINFORCED CONCRETE BEAMS

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Reinforced concrete structures subjected to loads that cause the formation and propagation of cracks exhibit a behavior where continuum mechanics is no longer applicable, because most conventional models do not consider the discontinuities that appear and propagate as a result of concrete tension failure. In an effort to correct the shortcomings of continuum models, the peridynamic bond-based model was proposed in 2000 and the peridynamic state-based model in 2007.

Using the peridynamic stress tensor notion introduced by Silling and Lehoucq, the stress tensor can be used to calculate the stress tensor in regions where the displacement field is discontinuous. Nevertheless, this approach can only be used for fixed values of the Poisson´s ratio. The micropolar peridynamic model improves the bond-based peridynamic model by allowing different values of the Poisson´s ratio. A numerical scheme for the calculation of the micropolar peridynamic stress was developed where results show convergence with classical linear elastic solutions for small values of the material horizon.

Strength capacity of reinforced concrete beams has not been easy to predict with the use of non-empirical methods, since most conventional models do not consider the discontinuities that appear and propagate as a result of concrete tension failure. Strength of plain and reinforced concrete beams has been analyzed using the peridynamic and non-local models. However, design codes depend on the stress distribution at critical points in the beams. With this approach, the stress tensor can be analyzed at any point in failure zones. By means of three and four point reinforced concrete beam tests, strength is obtained and compared with the model.

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# INFLUENCE OF FRICTION REDUCTION PAD ON THE MECHANICAL BEHAVIOR OF CONCRETE SUBJECTED TO 3-D PASSIVE CONFINEMENT

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Numerous models have been proposed for dilation phenomenon of passively confined concrete subjected to uniaxial loading condition. However, concrete structures are usually under passive multiaxial stress state such as 3-dimensional (3-D) stress. Meanwhile, little studies have examined the mechanical behavior of concrete under this loading condition. In addition, the effects of friction reduction pads on the strength and dilation properties of the passively confined concrete have received little attention. Thereby, few experimental data are available for the calibration and validation of material parameters and response under this scenario. With a novel 3-D testing system, fabricated at City University of Hong Kong, to produce passive confinement, concrete cubes were tested to examine its mechanical behavior under such loading condition and influence of friction reduction pads.

Keywords: Concrete, Dilation, 3-D stress, Passive confinement, Friction reduction pads.

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# UNIFIED THEORY OF STRUCTURES BASED ON MICROPOLAR ELASTICITY

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Classical theory of linear elasticity is the common practice in engineering. It assumes that the rotations within the continuum are a direct consequence of displacements and the interaction between adjacent points occur only by means of translational forces. The classical theory of linear elasticity has produced acceptable results for various applications. However, when large stress gradients or significant microstructure contributions occur within the structure (e.g., in the proximity of holes and cracks), classical theories may fail. In fact, recent experiments have shown that materials will display strong scale effects as the deformations are small compared to a characteristic length. Moreover, the trend of miniaturization in engineering, such as micro-electro-mechanical systems (MEMS) and electronic materials, requires a comprehensive understanding of microstructural effects on the macroscopic response of the structure. In this framework, micropolar elasticity was developed to overcome these issues. This theory considers the structure as a continuous distribution of particles. Each particle can make not only translations but also microrotations. As a consequence, the solid can bear not only stresses, but also couple stresses.

This paper intends to establish a unified theory of structure based on the micropolar elasticity. The solution proposed is developed in the domain of the Carrera Unified Formulation (CUF), according to which theories of structures can degenerate into a generalized kinematics that makes use of an arbitrary expansion of the generalized variables. CUF is a hierarchical formulation that considers the order of the structural model as an input of the analysis, so that no specific formulations are needed to obtain any refined model.

Different types of structures have been analyzed and the results are compared and validated with examples found in the literature.

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# ACCURATE STRESS ANALYSIS OF BONDED JOINTS VIA HIGHER-ORDER MODELS

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Adhesive bonding techniques are increasingly being adopted in aerospace and mechanical engineering for composite applications due to their enhanced performance in comparison to mechanical joints, which provoke preliminary damage and local concentration of stresses. Still, the accurate evaluation of the stress fields that arise at the bonded areas is of paramount importance to predict the mechanical response of the structural component and the associated failure envelopes. In order to reduce the complexity and the computational size of the numerical simulation of adhesive joints, the present study proposes the use higher-order beam models based on the Carrera Unified Formulation (CUF). The idea is to reduce the 3D problem to a 1D analysis based on advanced beam elements which provide 3D-like stress solutions with reduced computational efforts. In the CUF framework, the three-dimensional displacements field is expressed as an arbitrary expansion of the generalized displacements over the cross-section coordinates. For the purposes of this study, a Legendre-based polynomial expansion, named as Hierarchical Legendre Expansion, is employed to interpolate the displacement unknowns over the domain, allowing the user to enrich the model locally in the bonded zone between adherents. The focus of this study is to compute the stress singularities that arise at the interfaces and free-edges of the adhesive. The numerical efficiency of the proposed methodology is assessed through comparison against references from the literature and commercial FEM codes.

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# ADVANCED MODELS FOR THE NONLINEAR STATIC RESPONSE OF BIOLOGICAL STRUCTURES

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The results of an elastoplastic analysis of classical bio-structures via refined beam models are here presented.

In this work, an atherosclerotic plaque is taken into account as a typical bio-structure example with complex features and analyzed under both linear and non-linear assumptions, via one-dimensional kinematic models. Specific attention is paid to the evaluation of local effects and of the stress/strain distribution both in- and out-of-plane in the presence of different boundary conditions. The von Mises plasticity model is considered to account for the material nonlinearity, and the solution of the nonlinear algebraic equations is accomplished by the Newton-Raphson method.

This elastoplastic analysis is performed through the application of the Carrera Unified Formulation (CUF). The CUF is a higher-order one-dimensional theory in which the kinematics of the problem depends only on the expansion of the generalized unknown. Two kinds of cross-section expansion functions, Taylor's and Lagrange's polynomials, are adopted to model the structure, and finite element method (FEM) is used to formulate the governing equations. This technique allows reaching 3D-like results without any simplification of the geometry, avoiding the high computational effort, common in this kind of applications.

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# CONCEPT OF A HUMAN RESPONSE MODEL FOR AIRCRAFT CABIN INTERIORS DESIGN IN VIRTUAL ENVIRONMENTS

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In the earliest stages of industrial products design process several tools and methods are needed for the evaluation of alternative solutions. Those methods allow designers to account for the humans that will interact with such products with the aim of enhancing the quality of the solutions from the user's point of view. This implies that designers should be able to precisely estimate the impact of any design feature on the ergonomic, usability and perceived comfort aspects. The main issues in this process are the manufacturing time and costs of physical mock-ups and the efficiency of the methods used to capture the user's perception in terms of feelings inspired by different concepts or product configurations. In several cases Virtual mock ups can be used to run simulations of the human-product interaction overcoming the need of physical specimens. On the evaluation side, it is known that in the current practice positive or negative feelings are associated to the level of comfort and well-being self reported by the user as a qualitative assessment of a product or service. Therefore, the evaluation of alternative configurations is commonly based on subjective ratings that participants perform by filling questionnaires during or after experiencing a prototype of the product. In this talk we present the concept of a human response model that has been conceived and will be implemented in the framework of the CASTLE project (CAbin Systems design Toward passenger welLbEing). The aim is to investigate how a set of physiological measures and Virtual Reality can support the early design of aircraft cabin interiors from the emotional point of view bringing advantages such as reduction of costs for the company, reduction of the time to market and improvement of the overall Human Centered Design process. The final output is the definition of innovative design methods to objectively measure the affective impact on a potential user when interacting with a product.

**Keywords** Human Centered Design; Emotional Design; Virtual Reality; Brain Computer Interfaces; Comfort, Aircraft Design.

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# THERMOELASTICITY WITH SECOND SOUND IN VARIABLE THICKNESS DISKS VIA CARRERA UNIFIED FORMULATION

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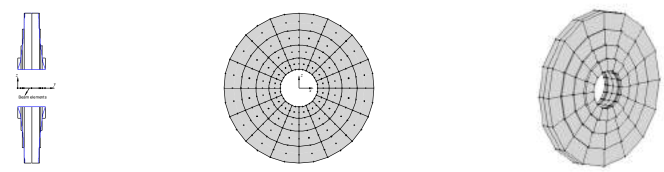
In this research, based on the Lord-Shulman generalized coupled thermoelasticity theory, propagation of the 3D thermoelastic waves and the second sound effect in variable thickness disks are investigated. To simultaneously solve the equations of motion and the energy equation, a traditional 1D finite element method refined through the Carrera Unified Formulation (So-called 1D FE-CUF method) is employed. Eventually, the final matrix form of the equations is solved in the Laplace transform domain and then, the transformed solutions are numerically inverted to obtain the physical responses in the time domain. According to the 1D FE-CUF method, 3D descriptions of the three displacement components and the temperature change can be approximated as

$$\boldsymbol{u}(x,y,z,t) = F_\tau(x,z)N_m(y)\boldsymbol{U}_{\tau m}(t)$$
$$T(x,y,z,t) = F_\tau(x,z)N_m(y)\theta_{\tau m}(t)$$

In this method, a disk is discretized along its axis ($y$-axis) into a finite number of 1D elements to interpolate the displacement and temperature variables, while the bi-dimensional functions $F_\tau$ describe state of the variables over cross-sections of the model. Therefore, the index $m$ ranges from 1 to the number of nodes within the adopted 1D element, and can be 2, 3 or 4. In the present work, the N-order Lagrange polynomials are selected as the functions $F_\tau$. Then, the index $\tau$ rages from 1 to the number of points of Lagrange element used over the cross-section. Figure 1 shows a 1D FE-CUF model of variable thickness disk.

Indeed, using the method, 3D thermoelastic problems can be reduced to 1D models with 3D-like accuracies. Since the time history analysis of the dynamic problems is very time consuming, the reduced models have been recommended to obtain the solutions with lower computational effort. The validity and capabilities of the method and convergence of results are demonstrated in a number of numerical examples. Moreover, the propagation of thermoelastic waves and their reflection from the boundaries in a disk exposed to a temperature shock are illustrated (see Fig. 2).



8 two-node element    4×16 nine-point element    Computational model

Figure 1 A 1D FE-CUF model of variable thickness disk.

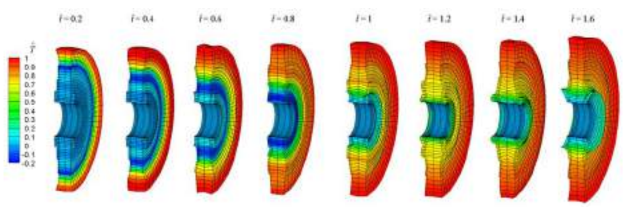


Figure 2 Second sound effect in a disk exposed to a temperature shock.

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# The rigid-body plastic analysis of free-end torsion problem using a newly developed constitutive equation based on the plastic spin concept

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A constitutive equation for the rigid-plastic response of the material is proposed by the combination of the plastic spin tensor and the distortional yield function. To complete the model, the isotropic, kinematic and distortional hardening parameters are incorporated into the yield function. The corresponding associated-flow rule responses to the variations of the deformation rate tensor and the Cauchy stress are investigated. Using the proposed model, the macroscopic plastic spin tensor is derived and incorporated into the constitutive equations to transform the proposed model to a co-rotational system. The Jauman, Green-Naghdi, Eulerian and Lagrangian co-rotational rates are applied on the model and the results are compared to the results of the proposed co-rotational rate. The proposed model shows good agreement with the experimental results of the free-end torsion of the SUS-304. It is also proven that the proper adjustment of the Dafalias's constant in the proposed model with the plastic spin co-rotational rate can cover the results of the other co-rotational rates.

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# Vibration control of a footbridge using a vibration absorber integrating a magnetorheological brake

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Many Civil Structures have vibration problems in terms of serviceability limit states due to several transient or periodic dynamic loads, e.g., footbridges subjected to pedestrian actions, road and railway bridges excited by traffic loads and tall buildings exposed to wind forces. In these situations, the implementation of control systems can improve the structural performance by reducing the vibration levels to acceptable values, which are established for each case. When controlling harmonic vibrations, one of the most interesting and common devices is the vibration absorber, also known as Tuned Mass Damper (TMD). However, these devices may have some functioning problems common to passive systems. In fact, because they are purely passive, they don't have the possibility of adapting themselves to the actual characteristics of the external actions or to the identified structural properties. One possible way to solve this problem is to use active TMDs, which are not so attractive solution in Civil Engineering because of their cost, particularly dealing with large structures. Indeed, they require sophisticated technology as well as powerful actuators and energy supply, which also calls for a lot of maintenance. For these reasons, in last few years, special attention has been given to semi-active systems which are still based on feedback control schemes, but require much simpler technology and actuators, and much less energy.

In this context, this paper presents the research work involving the development of a semi-active TMD used to reduce vibrations in a slender footbridge. Two of these devices are currently installed in the structure and working in passive mode. On the other hand, a prototype of the semi-active TMD was tested in laboratory in order to verify its correct functioning, aiming the upgrading of the control devices to the semi-active mode. This particular type of semi-active TMD integrates a magnetorheological brake in its functioning, which is used to control the motion of the inertial mass by imposing of an adequate phase angle between the motion of the structure and the TMD. This will correct the problems of the passive control system by allowing it to operate in a wide frequency range, enabling the self-tuning of the TMD as well as the possibility of performing multimode control. This paper gives particular attention to the characterization of the performance of the passive control during the last 2 years, and discuss the results obtained in terms of the expected improvement in moving from a passive system to a semi-active system.

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# Anomalous Fracture Behavior of Graphene due to Nano-scale Size Effect

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A study of transition crack length for a nano-graphene system is presented in this article as verification of our macro-scale theoretical predictions and experimental observations, in an effort to explain the frequently observed deviation of fracture toughness of nanocomposites from LEFM predictions. Using a value of theoretical strength for graphene of 118 GPa, and $K_{IC}$ =2.725 $MPa\sqrt{m}$ , the $a_{cr}$ for graphene is obtained as 2.387Å. Nano-scale molecular dynamics (MD) simulations were carried out on a single nano-graphene platelet of 10 nm x 20 nm dimensions with zigzag chirality in using LAMMPS. Figure 1(a) shows a typical case of a sheet with initial half-crack length of 16.435 Å created by removing twelve hexagonal carbon lattices at the center. End grips were vertically displaced about the mid-plane to produce tensile strain at the rate of 0.1 per picosecond in NVT environment maintained at room temperature (300 K). Virial stress at failure were computed at the far-field, and far field stress obtained through post-processing for various pre-crack lengths which are plotted as shown in Figure 1(b). Failure stress for defect free graphene is found to be about 118 GPa from MD simulation which agrees well with the theoretical strength of graphene thereby benchmarking the atomistic model. Further, the critical crack length is predicted to be approximately 2.525 Å from the MD simulation below which anomalous deviation from LEFM prediction is observed (See Fig. 1(b)).

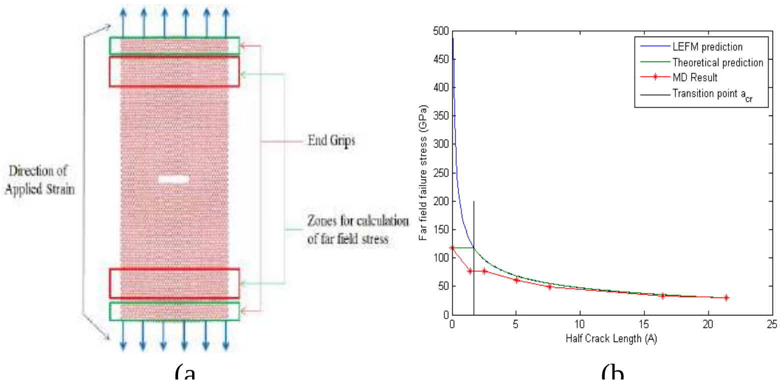


Figure 1: a) A typical pre-cracked Nano-Graphene sheet; b) Deviation of atomistic prediction from LEFM prediction due to flaw size effect

Work is currently underway to determine how nanoparticles can be employed as matrix reinforcement of optimized size to maintain a flaw size less than the critical value such that debond cracks along nanoparticle-polymer interface will remain below a critical length scale thereby enhancing toughness.

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# NODE-DEPENDENT KINEMATIC ELEMENTS FOR THE ANALYSIS OF ENERGY HARVESTER

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The development of advanced materials, such as the piezo-electric material, has lead to the design of small devices able to exploit the electro-mechanical coupling to actuate, monitoring, extract energy or control structures of different nature. These devices can be used to produce small quantities of energy but large enough to supply wireless sensors or monitoring systems. The design of such structures requires to predict complex phenomena such as: electro-mechanical coupling, stress concentrations at the interface between the active material and the substrate layers, complex boundary conditions, etc. The performances of these smart structures may be enhanced by an accurate design of the dynamic response of the structure. A large number of advanced models, able to deal with such complex problems, have been proposed over the last decades. These models, usually based on advanced kinematic descriptions or three-dimensional solutions, requires huge computational costs and can be applied in a portion of the structure.

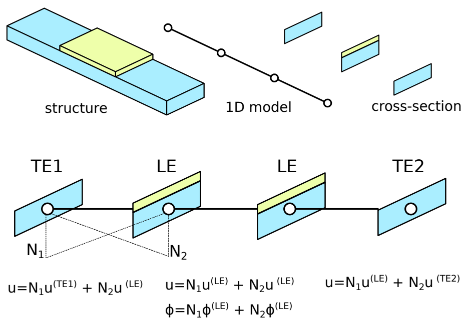


Figure 1: An example of a NDK model for piezo-patched structures.

This work extends the use of one-dimensional elements with node-dependent kinematics (NDK) to the analysis of energy harvester. NDK allows the kinematic assumptions to be defined individually on each finite element (FE) node, leading to FE models with variable nodal kinematics. Derived from Carrera Unified Formulation (CUF), NDK facilitates the mathematical refinement to an arbitrary order at any desirable region on the nodal level while keeping the compactness of the formulation. NDK is applied to increase the numerical accuracy in the areas where the smart material patches lie in through sufficiently refined models, while lower order assumptions are used elsewhere. NDK models capabilities can be exploited in combination with the component-wise approach in order to study complex structures. The results are compared against those from literature. The numerical study shows that the adoption of NDK allows accurate results to be obtained at reduced computational costs.

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# COMPONENT-WISE MODELS FOR THE ANALYSIS OF COMPOSITE STRUCTURES EXPOSED TO AGING PHENOMENA

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Composite materials are progressively replacing the conventional metallic materials, especially in aeronautical applications, by contributing to significant weight and cost savings. The benefit of these kinds of materials lies in their enhanced specific strength and stiffness, design flexibility, long life. The presence of the polymeric matrix makes fiber-reinforced composite materials liable to absorb moisture in a humid environment, eventually at elevated temperatures and, in general, to undergo detrimental aging phenomena if exposed to atmospheric condition. The phenomenon of aging can be depicted as a gradual process in which the properties of a material, structure, or system, change (for better or worse) over time or with use, due to biological, chemical, or physical agents; corrosion, obsolescence, and weathering are examples of aging. The prediction of the mechanical response of composite structures exposed to aging phenomena is crucial to avoid the structural failure, that is, appropriate numerical tools must be adopted. Since the aging acts differently on the polymeric matrix and the carbon fiber the classical models may lead to inaccurate results when homogenized materials are considered.

The present paper aims to extend the use of refined one-dimensional models to the analysis of aged composite structures. The use of the component-wise approach allows the matrix and the fibers to be considered as independent entities. The introduction of refined kinematic approximations leads to a three-dimensional solution. The Carrera Unified Formulation has been used to derive the formulation in a compact and general form. The effect of the aging phenomena, in particular, due to the UV light exposition, has been introduced with a reduction of the material properties following the results presented in the literature. The present models have been used to investigate the effects of the aging phenomena on the structural response and the distribution of the internal stress field. The results show that the aging can generally affect the structural response. The more dramatic effects can be seen at the local level where the reduction of the matrix performances leads to a substantial variation in the stress field.

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# ANALYSES OF VAT COMPOSITE STRUCTURES USING A LAYER-WISE 1D MODEL

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The research is engaged in the optimization of the composite laminates because of their extensive use in many engineering fields. Typically these materials are defined as Constant Stiffness Composite laminate (CSCL) characterized by the same stiffness, that is determined by the layers which compose the laminate, over the whole component. The new additive manufacturing technologies, such as the Automated Fibre Placement (AFP), offer new design rules that overcome the constraint of the classical laminates where the layers have straight fibers along one direction. AFP technology allows the fiber of each layer to be placed along a curvilinear path defined by the designer. This feature introduces a wide range of tailoring scenarios making possible to find more efficient solutions than before, in fact, Variable Stiffness Composite laminates (VSCL) can be achieved with no discontinuities in the material. These new class of composite materials, named Variable Angle Tow (VAT) composites are in the spotlights, and new models able to predict their mechanical behaviors have to be developed to not compromise the design process. Through the VAT composites, the designer has excellent control on several aspects such as the redirection of the stress fluxes, local stiffness increases, control of the vibrational behavior or the introduction of coupling effects. Because of the limited capacities of the classical theories, refined models are required to provide an accurate prediction of the complex mechanical behaviors of these materials. Besides, these models must be able to evaluate the material proprieties point by point over the whole component. Refined beam models based on the Carrera Unified Formulation (CUF) has been extended to the analyses of VAT composites in this work. The 1D CUF model uses expansions to approximate the displacement field over the cross-section in the definition of the model kinematics. Accordingly to the used expansion, equivalent single layer or layer-wise models can be achieved. The work proposes free-vibration analyses of VAT laminates using results from the open literature. Thin-walled boxes are also taken into account, and the influences of curvilinear fibers on the modal behavior have been evaluated.

# CONCEPTUAL DESIGN AND ANALYSIS OF A MULTI-COMPONENT INTERBODY FUSION DEVICE

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The intervertebral disc degeneration causes spinal disease which represents a serious medical problem affecting many people worldwide. Currently, disc arthroplasty, discectomy and fusion may be considered the most common surgical approaches in the case of disc degenerative disease. In this context, intervertebral spacers such as titanium cylinders and mesh cages are generally considered to restore and maintain the physiological disc height. Accordingly, in the current research a metal interbody fusion device was proposed to be implanted through a minimally invasive surgical approach. The design of the proposed metal device was carried out taking into account the possibility to properly increase and to decrease the height, as well as to introduce the system through a medical cannula. In particular, a double-threaded screw was also designed to modulate the height of the system. Different components and technological solutions were considered to develop the system. Computer-Aided Design (CAD) and Finite Element Analysis (FEA) were integrated to study the biomechanical behavior of the multi-component metal device using different configurations (Figure 1). The effect of geometry/configuration on the stress and strain distributions was investigated, providing interesting results. Furthermore, the theoretical model was also employed to verify the design parameters.

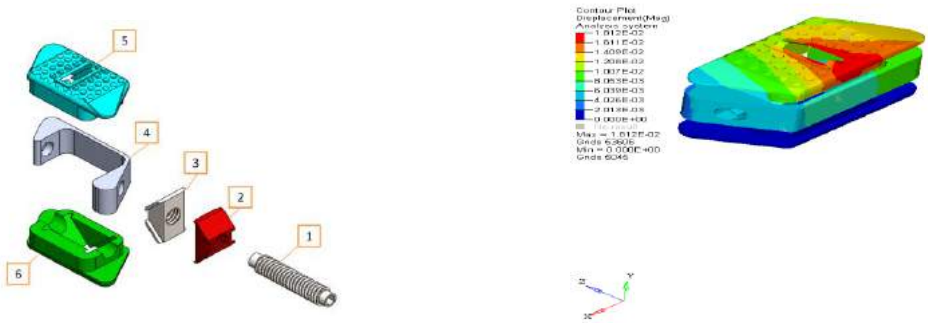


Figure 1. Different components of the proposed interbody fusion device (left); typical results from FEA (right).

# METAL POSTS AND EFFECT OF MATERIAL-SHAPE COMBINATION ON THE MECHANICAL BEHAVIOUR OF ENDODONTICALLY TREATED ANTERIOR TEETH

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Posts with varied materials, sizes and shapes are usually considered for clinical use by endodontists. Several dental post-core systems have been proposed and metal posts were initially employed. Even though it has been frequently reported that the great mismatch between the elastic modulus of metal posts and surrounding structures causes stress concentration and root fracture, it is also worth noting that stress distributions are related to the stiffness, which depends upon the Young's modulus (an intrinsic mechanical property of the material) and shape and size. A micro-CT scanner system was employed to digitize an intact canine. The geometric models of endodontically treated anterior teeth were imported into HyperMesh® (HyperWorks® - 14.0, Altair Engineering Inc.). Four models were built-up and analysed using finite element analysis. Specifically, metal posts (titanium and nickel-chromium alloy) with conical–tapered shape and conical–cylindrical shape were considered. A load of 100 N was applied at 45° to the longitudinal axis of the tooth. Stress distributions were evaluated along the post and at the interface between the post and the surrounding structure. The obtained results evidenced that the material-shape combination played an important role, influencing the mechanical behavior of endodontically treated anterior teeth (Figure 1).

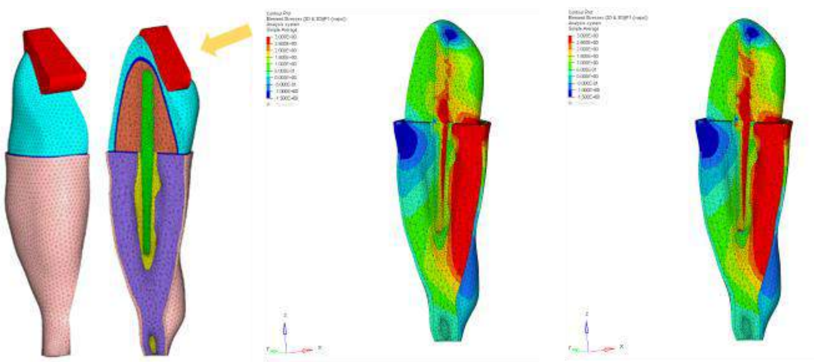

Figure 1. Model of endodontically treated tooth and typical results from finite element analysis.

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# MATERIAL CHARCTERIZATION AND MODELING OF GRAPHENE NANOPLATELETS REINFORCED COMPOSITED FOR ICME STUDIES

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The use of polymer/graphene nanocomposites is expanding in many engineering applications including, electronics, additive manufacturing, energy storage devices and advanced composites. In particular, graphene nano-platelets high conductivity is leading to the development of thermally enhanced carbon fiber reinforced composites. Integrated, predictive multiscale modeling techniques of materials and systems accounting for manufacturing are a key aspect for the development of the next generation of structures for aerospace applications in an efficient and cost effective manner. Development of such modeling strategies aligns with the Integrated Computational Materials Engineering (ICME) and the Material Genome initiatives (MGI).

The primary goal of this research is to establish critical linkages between nano-reinforced polymers, process models and curing induced residual stress for the enhancement of Integrated Computational Materials Engineering (ICME) approaches for nanocomposites. Understanding the effect of nano-reinforcement on thermomechanical properties of fiber-reinforced composites during curing is needed to develop new computational techniques that account for manufacturing. In-depth studies require extensive material characterization of the nano-reinforced materials as function of the curing process. In this work, results are presented for graphene-reinforced Epoxy, with graphene weight fractions ranging from 0.3 wt% to 1.6 wt%. The effect of graphene nano-platelets on resin properties are determined from thermo-mechanical testing. First, cure kinetics, elastic and thermal properties of the nanocomposites as a function of graphene content are characterized during curing. Then, virtual tools are used for the prediction of residual stress during curing using an instantaneous linear elastic model. Modeling is performed using the Finite Element Method (FEM). The commercial available software, ABAQUS is used as the FEM solver, supplemented by user written subroutines.

# Modeling-Driven Design of Spacecraft Hardware with Improved Shear Toughening Using Graphene Nanoplatelet/Carbon Fiber/Epoxy Hybrid Composites

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Carbon/epoxy composite materials play a critical role in modern aerospace design. While carbon/epoxy composites are already used in many current aerospace structures, continued material development is desired for improved mechanical performance. Specifically, it is desired to use composite laminates in the facesheets of sandwich panels used for the barrel section of launch vehicles, where open hole compression (OHC) strength is a key parameter that needs to be optimized to ensure damage tolerant designs[1, 2] Because large curved structures are subject to geometric imperfections and impact damage, the designs must utilize additional knockdown factors on top of the standard safety factor, as well as damage tolerant material properties. Thus, they can be overdesigned, and any increase in the OHC strength of the structure can yield significant weight savings.

Recently, Hadden et al. [3] introduced a multiscale modeling method specifically designed for carbon fiber (CF)/epoxy composites that incorporates graphene nanoparticles (GNP) into the epoxy matrix for added stiffness. For these CF/GNP/epoxy hybrid composites, the modeling method included material characteristics of different length scales (nanoscopic and microscopic) to predict bulk-level elastic properties with a unidirectional CF orientation. It was found that the incorporation of GNP into the epoxy matrix has a significant impact on some of the elastic properties of the unidirectional hybrid composite. Furthermore, it was found that improvements in GNP dispersion could also have a strong effect on transverse properties. However, their study did not address non-linear behavior of the material, such as OHC strength, or laminate architecture.

OHC strength of fiber-reinforced composite laminates is controlled by the shear response of the surrounding matrix.[4] As the laminate is loaded in compression, the fibers in the plies rotate which induces an increase in the shear strain. The elevation shear strain promotes microcracking in the matrix, degrading the shear stiffness. The reduction of the shear stiffness allows for additional rotation of the fibers. Thus, the fiber rotation, shear strain evolution, and matrix degradation are coupled and their effects are compounding. This ultimately leads to an instability failure during which a fiber kink band forms due to fiber microbuckling. Previous computational and experimental work has shown that the addition of GNP can increase the fracture toughness of

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# MODELING OF COMPOSITE STRUCTURES WITH PIEZOELECTRIC COMPONENTS BY REFINED FINITE ELEMENTS

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This work presents a practical finite element (FE) modeling approach for the simulation of laminated structures with piezoelectric layers and patches. A great variety of advanced electro-mechanical models can be integrated to obtain refined elements in the framework of Carrera Unified Formulation (CUF) [1, 2]. Through the so-called *fundamental nuclei*, whose form is independent of the kinematic assumptions made over the section of 1D/2D models, refined FE models with variable kinematics can be conveniently constructed. Derived from CUF, node-dependent kinematics (NDK) can help to facilitate the local enrichment of the displacement/electric field on a nodal basis, and enable the FE models to possess variable Equivalent-single-layer/Layer-wise capabilities. Through the Layer-wise model, the dissimilar material domains are separated as different sectional domains. NDK is a suitable technique for the modeling of laminated structures with local piezoelectric components. In the present work, the simulation approach of piezoelectric embedded layers and surface-mounted segmented patches by NDK refined FE models is demonstrated. The numerical accuracy is improved by enriching the kinematic theories while the efficiency is guaranteed through NDK-type local kinematic refinement within the critical region. The numerical results achieved are compared against those obtained with commercial software.

*References*

[1] *Carrera E., Brischetto S. and Nali P., Plates and shells for smart structures: classical and advanced theories for modeling and analysis, John Wiley & Sons (2011).*

[2] *Carrera, E., Cinefra, M., Petrolo, M., Zappino, E., Finite element analysis of structures through Unified Formulation, John Wiley & Sons (2014).*

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# SURROGATE MODELLING OF AEROSPACE STRUCTURES FOR DAMAGE DETECTION AND CLASSIFICATION

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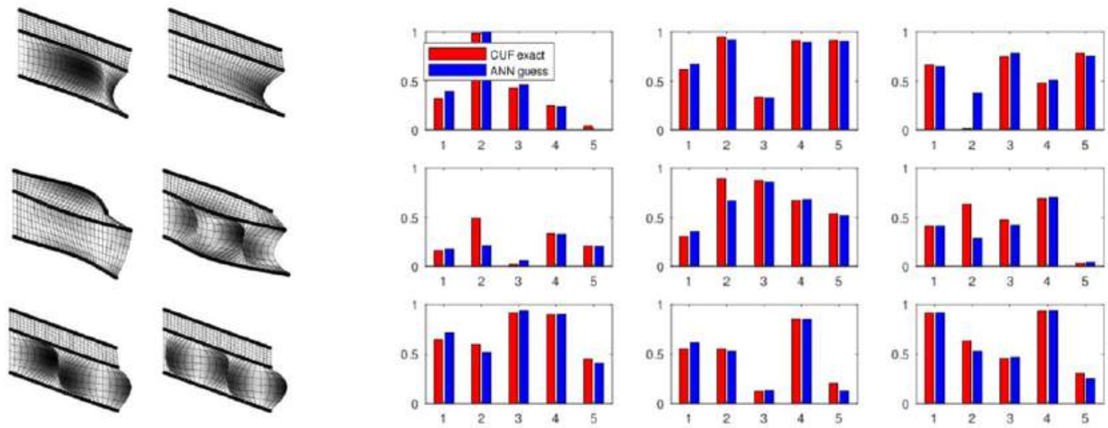
Artificial neural networks (ANNs) are inspired by the impressive cognitive and data processing capabilities that are typical of biological neural networks and have been widely employed in the last few decades for various engineering applications, including image processing, pattern recognition, diagnostic systems, and complex function approximations. In this work, multilayer perceptrons are utilized for vibration-based damage detection of multi-component aerospace structures. A back-propagation algorithm is utilized along with Monte Carlo simulations and advanced structural theories for training ANNs, which are able to detect and classify local damages in structures given the natural frequencies and the associated vibrations modes. The latter ones are feed into the network in terms of Modal Assurance Criterion (MAC), which is a scalar representing the degree of consistency between undamaged and damaged modal vectors.




(a) Representative vibration modes of damaged structure

(b) Damage detection by ANN

Figure 1: Component-wise damage detection of a three-stringer spar.

Dataset and ANN training process is carried out by means of Carrera Unified Formulation (CUF), according to which refined structural theories with component-wise capabilities can be implemented in a hierarchical and unified manner. As demonstrated in previous works [1], CUF is able to provide vibration characteristics of structures for a wide range of damage scenarios, see Fig. 1a. In this manner, trained ANNs can approximate complete mapping of the damage distribution, even in case of low damage intensities