Ali Sayigh *Editor*

Renewable Energy in the Service of Mankind Vol I

Selected Topics from the World Renewable Energy Congress WREC 2014

Springer

Renewable Energy in the Service of Mankind Vol I

Ali Sayigh
Editor

Renewable Energy in the Service of Mankind Vol I

Selected Topics from the World Renewable Energy Congress WREC 2014

Springer

Editor
Ali Sayigh
Chairman
World Renewable Energy Congress
Brighton
United Kingdom

ISBN 978-3-319-17776-2 ISBN 978-3-319-17777-9 (eBook)
DOI 10.1007/978-3-319-17777-9

Library of Congress Control Number: 2015947131

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Contents

Contributors

Ismaeil K. Abdou Egyptian Petroleum Research Institute, Nasr City, Cairo, Egypt

Ghanim Kadhim Abdulsada Department of Mechanical Engineering, Al-Mustansiriyah University, Baghdad, Iraq

Jorge Aguilera Tejero School of Architecture, University of Malaga, Málaga, Spain

Sheikh Saeed Ahmad Rawalpindi, Pakistan

Jong-Bo Ahn Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Republic of Korea

Amela Ajanovic Vienna University of Technology, Vienna, Austria

Mounir Aksas Energetics Applied Physics Laboratory, Department of Material Physics, Faculty of Sciences, Hadj Lakhdar University, Batna, Algeria

Khaled A. Al-Sallal Department of Architectural Engineering, UAE University, Al-Ain, United Arab Emirates

K. Amalevičiūtė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Kėdainiai district, Lithuania

Lennart Andersson Volvo Group Trucks Technology, Advanced Engineering & Research, Gothenburg, Sweden

Ronnie Andersson Chalmers University of Technology, Gothenburg, Sweden

Fredrik Andreasson Alfa Laval AB, Lund, Sweden

Xuereb Annalise University of Malta, Msida, MSD, Malta

A. R. M. Ariffin Department of Architecture, University of Malaya, Kuala Lumpur, Malaysia

Francisco Eduardo Arruda Rodrigues Curso de Licenciatura em Química, Instituto Federal da Paraíba—Campus Sousa, Fortaleza, Brazil

Eyjolfur Ingi Asgeirsson School of Science and Engineering, Reykjavik University, Reykjavik, Iceland

Solange Assunção Quintella Curso de pós-graduação em Química, Universidade Federal do Ceará, Fortaleza, Brazil

Mona Azarbayjani Integrated Design Labs, Energy Performance Laboratory, School of Architecture, College of Arts + Architecture, University of North Carolina at Charlotte, Charlotte, NC, USA

F Azizpour Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

L-V. Bénet Socotec Industries, Montigny-le-Bretonneux, France

Viorel Badescu Faculty of Mechanical Engineering and Mechatronics, Thermodynamics Department, Polytechnic University of Bucharest, Bucharest, Romania

Manoel Barbosa Dantas Curso de Licenciatura em Química, Instituto Federal da Paraíba—Campus Sousa, Fortaleza, Brazil

Jorge Barrios Corpa School of Architecture, University of Malaga, Málaga, Spain

Syeda Qamar Batool Rawalpindi, Pakistan

Olivier Baume Resource Centre for Environmental Technologies—Public Research Centre Henri Tudor, Esch-sur-Alzette, Luxembourg

Peter Bayer Department of Earth Sciences, ETH Zurich, Zurich, Switzerland

Markus Beck Wilhelm-Schickard-Institute for Computer Science (WSI), University of Tübingen, Tübingen, Germany

H. Bencheikh Laboratoire de génie civil, Université Amar Telidji, Laghouat, Algeria

Jörg Bendfeld Department of Sustainable Energy Concepts, University of Paderborn, Paderborn, Germany

Hyun Beom-Soo Division of Naval Architecture and Ocean System Engineering, Korea Maritime and Ocean University, Busan, Korea

Julian D. Booker Faculty of Engineering, University of Bristol, Bristol, UK

Matthew Bouchet School of Engineering, Robert Gordon University, Aberdeen, UK

Yassin Bouyraaman Department of Sustainable Energy Concepts, University of Paderborn, Paderborn, Germany

Christian Braun Resource Centre for Environmental Technologies—Public Research Centre Henri Tudor, Esch-sur-Alzette, Luxembourg

Dan J L Brett Electrochemical Innovation Lab, Department of Chemical Engineering, University College London (UCL), London, UK

Philipp Breymann Department of Sustainable Energy Concepts, University of Paderborn, Paderborn, Germany

Klaus Broekel Institute of Engineering Design/CAD, University of Rostock, Rostock, Germany

B. Butkutė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Kėdainiai district, Lithuania

Juan de la Casa Higueras School of Architecture, University of Malaga, Málaga, Spain

Valentina Cecchi Integrated Design Labs, Energy Performance Laboratory, School of Architecture, College of Arts + Architecture, University of North Carolina at Charlotte, Charlotte, NC, USA

J. Cesevičienė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Kėdainiai district, Lithuania

Priyanka Chawla Department of Chemistry, C.M.P. Degree College, University of Allahabad, Allahabad, India

Kai Chen School of Architecture, Harbin Institute of Technology, Harbin, China

Diego Chulde National Institute of Energy Efficiency and Renewable Energy (INER), Quito, Ecuador

Dania González Couret Faculty of Architecture, Instituto Superior Poiltécnico José Antonio Acheverría, Havana, Cuba

Cristiana Croitoru Building Services Department, Technical University of Civil Engineering in Bucharest, Bucharest, Romania

Ruxandra Crutescu Faculty of Architecture, Spiru Haret University, Bucharest, Romania

Spiteri Staines Cyril University of Malta, Msida, MSD, Malta

G. Dabkevičienė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Akademija, Kėdainiai, Lithuania

Maitha M. Bin Dalmouk Department of Architectural Engineering, UAE University, Al-Ain, United Arab Emirates

Brynhildur Davidsdottir School of Engineering and Natural Sciences, Environment and Natural Resources, University of Iceland, Reykjavik, Iceland

Jazaer Dawody Volvo Group Trucks Technology, Advanced Engineering & Research, Gothenburg, Sweden

Zahir Dehouche Brunel University, Uxbridge, UK

Y.G. Dessouky Electrical and Control Engineering Department, Arab Academy for Science and Technology & Maritime Transport, Alexandria, Egypt

P. K. Dey Aston Business School, Aston University, Birmingham, UK

Vishaal Dhamotharan Department of Engineering Design, IIT Madras, Chennai, Tamilnadu, India

Richard M. Dinsdale Sustainable Environment Research Centre (SERC), Faculty of Computing Engineering and Science, University of South Wales, Pontypridd, Mid-Glamorgan, UK

K. Dogan School of Science and Technology, International Hellenic University, Thessaloniki, Greece

Xu Dong School of Architecture, Harbin Institute of Technology, Harbin, China

Nenad Doroslovac Faculty of Mining and Geology, Department of Hydrogeology, University of Belgrade, Belgrade, Serbia

David Thomas Duarte Arruda Curso de pós-graduação em Química, Universidade Federal do Ceará, Fortaleza, Brazil

A. El-Deberky Department of Architecture, Minya University, Minya, Egypt

Eriyatno Graduate School of Business Management, Bogor Agricultural University, Bogor, Indonesia

Sebastián Espinoza National Institute of Energy Efficiency and Renewable Energy (INER), Quito, Ecuador

Robert N. Farrugia Institute for Sustainable Energy and Department of Mechanical Engineering, University of Malta, Msida, MSD, Malta

A. M. Foley School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, UK

Matt Folley SPACE, Queen's University Belfast, Belfast, Northern Ireland

Eric S Fraga Electrochemical Innovation Lab, Department of Chemical Engineering, University College London (UCL), London, UK

Centre for Process Systems Engineering, Department of Chemical Engineering, University College London (UCL), London, UK

Carwyn Frost School of Engineering, Cardiff University, Cardiff, UK

Junichiro Fukutomi Institute of Science and Technology, The University of Tokushima, Tokushima-city, Japan

Ben Futrell Integrated Design Labs, Energy Performance Laboratory, School of Architecture, College of Arts + Architecture, University of North Carolina at Charlotte, Charlotte, NC, USA

Paola Gallo Department of Architecture DIDA, University of Florence, Florence, Italy

Alberto García Marín School of Architecture, University of Malaga, Málaga, Spain

M. Garoum Laboratoire d'Energétique, Matériaux et Environnement (LEME), Université Mohammed V Rabat-Agdal, EST de Salé, Salé Medina, Maroc

S. K. Ghosh Mechanical Engineering Department, Centre for Quality Management System, Jadavpur University, Kolkata, India

Moa Ziethèn Granlund Royal Institute of Technology, Stockholm, Sweden

Liam Griggs Faculty of Science, Engineering and Computing, Kingston University, London, UK

E. Gruzdevienė Upytė Experimental Station, Lithuanian Research Centre for Agriculture and Forestry, Panevėžys district, Lithuania

Nabil M Guirguis Housing and Building Research Center, Giza, Egypt

Fredrik Gunnarsson Chalmers University of Technology, Gothenburg, Sweden

Alan J. Guwy Sustainable Environment Research Centre (SERC), Faculty of Computing Engineering and Science, University of South Wales, Pontypridd, Mid-Glamorgan, UK

Kristian Gvozdenovic Royal HaskoningDHV, Rotterdam, The Netherlands

Faculty of the Built Environment, University of Technology Eindhoven, Eindhoven, The Netherlands

Hanna Härelind Chalmers University of Technology, Gothenburg, Sweden

Olle Högblom Chalmers University of Technology, Gothenburg, Sweden

Reinaldo Haas Department of Physics, Federal University of Santa Catarina, Florianópolis, Brazil

Reinhard Haas Vienna University of Technology, Vienna, Austria

Jana Hadler Institute of Engineering Design/CAD, University of Rostock, Rostock, Germany

M.S. Hamad Electrical and Control Engineering Department, Arab Academy for Science and Technology & Maritime Transport, Alexandria, Egypt

Mohamed Hamdy Department of Energy Technology, Aalto University, Espoo, Finland

Building Physics and System Unit, Eindhoven University of Technology, Eindhoven, The Netherlands

George Bassili Hanna Housing & Building National Research Center, Cairo, Egypt

Rolf Hansen LM Wind Power, Kolding, Denmark

Ala Hasan VTT Technical Research Centre of Finland, Espoo, Finland

Mahmoud A Hassan Housing and Building Research Center, Giza, Egypt

Rickard Heijl Chalmers University of Technology, Gothenburg, Sweden

Ebtisam K. Heikal Egyptian Petroleum Research Institute, Nasr City, Cairo, Egypt

P. Higgins School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, UK

Lennart Holmgren Termo-Gen AB, Lärbro, Sweden

Angus Hood School of Engineering, Robert Gordon University, Aberdeen, UK

Mamdud Hossain School of Engineering, Robert Gordon University, Aberdeen, UK

Iva Hrgovan Department of Wind Energy, Technical University of Denmark, Kongens Lyngby, Denmark

Jin Hwan Ko Korea institute of Ocean Science and Technology, Ansan, South Korea

Chulsang Hwang Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Republic of Korea

R. A. Ibrahim Electrical and Control Engineering Department, Arab Academy for Science and Technology & Maritime Transport, Alexandria, Egypt

Kim In-Chul Department of Mechanical Engineering, Graduate School, Korea Maritime and Ocean University, Busan, Korea

Sheikh Zahidul Islam School of Engineering, Robert Gordon University, Aberdeen, UK

Muhammad Azzam Ismail Department of Architecture, University of Malaya, Kuala Lumpur, Malaysia

Piyush Jadhav Department of Engineering Design, IIT Madras, Chennai, Tamilnadu, India

Serm Janjai Department of Physics, Solar Energy Research Laboratory, Silpakorn University, Nakhon Pathom, Thailand

Z. Jankauskienė Upytė Experimental Station, Lithuanian Research Centre for Agriculture and Forestry, Panevėžys district, Lithuania

Jin-Hong Jeon Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Republic of Korea

Hong Jin School of Architecture, Harbin Institute of Technology, Harbin, China

Jian Kang School of Architecture, Harbin Institute of Technology, Harbin, China

School of Architecture, University of Sheffield, Sheffield, UK

M.C. Katafygiotou Department of Environmental Science and Technology, Cyprus University of Technology, Limassol, Cyprus

Amandeep Kaur Sustainable Environment Research Centre (SERC), Faculty of Computing Engineering and Science, University of South Wales, Pontypridd, Mid-Glamorgan, UK

Nila I Keumala Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia

Fouad Khaldi Energetics Applied Physics Laboratory, Department of Material Physics, Faculty of Sciences, Hadj Lakhdar University, Batna, Algeria

Salah A. Khalil Egyptian Petroleum Research Institute, Nasr City, Cairo, Egypt

Eung-Sang Kim Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Republic of Korea

Gyeong-Hun Kim Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Republic of Korea

Jihoon Kim Korea institute of Ocean Science and Technology, Ansan, South Korea

Jong-Yul Kim Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Republic of Korea

Seul Ki Kim Smart Distribution Research Center, Korea Electrotechnology Research Institute, Changwon, Korea

Maria Kolokotroni Brunel University, Uxbridge, UK

T. Koutra Department of Environmental Science and Technology, Cyprus University of Technology, Limassol, Cyprus

Andrew Kozyn School of Engineering, University of Guelph, Guelph, ON, Canada

Stefan Krauter Department of Sustainable Energy Concepts, University of Paderborn, Paderborn, Germany

Kanzumba Kusakana Department of Electrical, Electronic and Computer Engineering, Central University of Technology, Free State, Bloemfontein, South Africa

David Arroyo López-Carro E.T.S. Ingenieros Industriales, Universidad de Valladolid, Valladolid, Spain

Jesús López-Villada National Institute of Energy Efficiency and Renewable Energy (INER), Quito, Ecuador

N. Laaroussi Laboratoire d'Energétique, Matériaux et Environnement (LEME), Université Mohammed V Rabat-Agdal, EST de Salé, Salé Medina, Maroc

F. Lacroux AREVA T&D, Paris La défense cedex, France

Per-Olof Larsson Höganäs AB, Höganäs, Sweden

Jonathan Leaver Department of Civil Engineering, Unitec Institute of Technology, Auckland, New Zealand

Kwang-Soo Lee Korea institute of Ocean Science and Technology, Ansan, South Korea

Evita H. Legowo Swiss German University, Serpong, Indonesia

N. Lemežienė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Akademija, Kėdainiai, Lithuania

Ulrich Leopold Resource Centre for Environmental Technologies—Public Research Centre Henri Tudor, Esch-sur-Alzette, Luxembourg

Baizhan Li Key Laboratory of Eco-environments in Three Gorges Reservoir Region, Ministry of Education, Chongqing University, Chongqing, China

National Centre for International Research of Low-Carbon and Green Buildings, Chongqing, China

Ming Li School of Architecture, Harbin Institute of Technology, Harbin, China

Xin-xin Li School of Architecture, Harbin Institute of Technology, Harbin, China

Ž. Liatukas Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Akademija, Kėdainiai, Lithuania

I. Liaudanskienė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Kėdainiai district, Lithuania

C. H Lim Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

Célio Loureiro Cavalcante Curso de pós-graduação em Química, Universidade Federal do Ceará, Fortaleza, Brazil

William David Lubitz School of Engineering, University of Guelph, Guelph, ON, Canada

Mulè Stagno Luciano Institute of Sustainable Energy, University of Malta, Msida, MSD, Malta

Wim Maassen Royal HaskoningDHV, Rotterdam, The Netherlands

Faculty of the Built Environment, University of Technology Eindhoven, Eindhoven, The Netherlands

Jesper Madsen LM Wind Power, Kolding, Denmark

Ch. Maragkos Soft Energy Applications and Environmental Protection Laboratory, Mechanical Engineering Department, Technological Educational Institute of Piraeus, Athens, Greece

M. Markides Department of Environmental Science and Technology, Cyprus University of Technology, Limassol, Cyprus

G. Martinopoulos School of Science and Technology, International Hellenic University, Thessaloniki, Greece

Allan Mason-Jones School of Engineering, Cardiff University, Cardiff, UK

Alessio Mastrucci Resource Centre for Environmental Technologies—Public Research Centre Henri Tudor, Esch-sur-Alzette, Luxembourg

Dipartimento di Ingegneria Civile, Edile e Architettura—Università Politecnica delle Marche, Ancona, Italy

S Mat Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

Ranjana Meena Department of Engineering Design, IIT Madras, Chennai, Tamilnadu, India

Dejan Milenic Faculty of Mining and Geology, Department of Hydrogeology, University of Belgrade, Belgrade, Serbia

Hossein Mirzaii Kingston University, London, UK

Faculty of Science, Engineering and Computing, Kingston University, London, UK

S Moghimi Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

Tathilene Bezerra Mota Gomes Arruda Curso de pós-graduação em Química, Universidade Federal do Ceará, Fortaleza, Brazil

K. Moustris Soft Energy Applications and Environmental Protection Laboratory, Mechanical Engineering Department, Technological Educational Institute of Piraeus, Athens, Greece

Helmut F. O. Mueller Green Building R&D, Duesseldorf, Germany

Navid Nahi Department of Architecture, East Azarbaijan Science and Research Branch, Islamic Azad University, Tabriz, Iran

Lee Nak-Joong Department of Mechanical Engineering, Graduate School, Korea Maritime and Ocean University, Busan, Korea

Ricardo A. Narváez C. National Institute of Energy Efficiency and Renewable Energy (INER), Quito, Ecuador

Centre for Renewable Energy Systems Technology (CREST), Loughborough University, Loughborough, UK

Ilinca Nastase Building Services Department, Technical University of Civil Engineering in Bucharest, Bucharest, Romania

Kanokwan Ngaosuwan Chemical Engineering Division, Engineering Faculty, Rajamangala University of Technology Krungthep, Bangkok, Thailand

J. D. Nixon Faculty of Science, Engineering and Computing, Kingston University, London, UK

E. Norkevičienė Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Akademija, Kėdainiai, Lithuania

Bubele Papy Numbi Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, South Africa

Daphne O'Doherty School of Engineering, Cardiff University, Cardiff, UK

Tim O'Doherty School of Engineering, Cardiff University, Cardiff, UK

Patrick R. Osborne Lee Evans Partnership, London, UK

Anders Palmqvist Chalmers University of Technology, Gothenburg, Sweden

Matti Palonen Department of Energy Technology, Aalto University, Espoo, Finland

Michael de Paly Wilhelm-Schickard-Institute for Computer Science (WSI), University of Tübingen, Tübingen, Germany

Nikos Papamanolis School of Architecture, Technical University of Crete, Chania, Greece

Jin-Soon Park Korea institute of Ocean Science and Technology, Ansan, South Korea

Joachim Pasel Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, IEK-3: Electrochemical Process Engineering, Jülich, Germany

Júlio C. Passos Department of Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brazil

Mechanical Engineering Department, Federal University of Santa Catarina, Florianópolis, Brazil

Ralf Peters Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, IEK-3: Electrochemical Process Engineering, Jülich, Germany

Lars J. Pettersson Royal Institute of Technology, Stockholm, Sweden

Poorang A.E. Piroozfar Division of Built Environment and Civil Engineering, School of Environment and Technology, University of Brighton, Brighton, UK

Francesco Pomponi Division of Built Environment and Civil Engineering, School of Environment and Technology, University of Brighton, Brighton, UK

Nágila Maria Pontes Silva Ricardo Curso de pós-graduação em Química, Universidade Federal do Ceará, Fortaleza, Brazil

Ruth Potopsingh University of Technology, Kingston, Jamaica

K. Arul Prakash Department of Applied Mechanics, IIT Madras, Chennai, Tamilnadu, India

Giuliano C. Premier Sustainable Environment Research Centre (SERC), Faculty of Computing Engineering and Science, University of South Wales, Pontypridd, Mid-Glamorgan, UK

Stephen Pretlove School of Architecture & Landscape, Kingston University London, Grange Road, UK

Tuyen Quang Le Korea institute of Ocean Science and Technology, Ansan, South Korea

Valeria Ramírez National Institute of Energy Efficiency and Renewable Energy (INER), Quito, Ecuador

Palaniappan Ramu Department of Engineering Design, IIT Madras, Chennai, Tamilnadu, India

A. Rizk Department of Architectural Engineering, Tanta University, Tanta, Egypt

Rosa Romano Department of Architecture DIDA, University of Florence, Florence, Italy

Krisztian Ronaszegi Electrochemical Innovation Lab, Department of Chemical Engineering, University College London (UCL), London, UK

N. Saboohi Department of Environmental Science and Technology, Cyprus University of Technology, Limassol, Cyprus

S. Sagi School of Engineering and Applied Science, Aston University, Birmingham, UK

Yoshiaki Sakagami Department of Health and Service, Federal Institute of Santa Catarina, Florianópolis, Brazil

Department of Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brazil

Yoshiaki Sakagami Health and Science Department, Federal Institution of Santa Catarina, Florianópolis, Brazil

Tawfeeq Wasmi M. Salih Department of Mechanical Engineering, Al-Mustansiriyah University, Baghdad, Iraq

E Salleh Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

Remzi Can Samsun Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, IEK-3: Electrochemical Process Engineering, Jülich, Germany

Tonio Sant Institute for Sustainable Energy and Department of Mechanical Engineering, University of Malta, Msida, MSD, Malta

Pedro A. A. Santos Department of Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brazil

Mechanical Engineering Department, Federal University of Santa Catarina, Florianópolis, Brazil

Aliyah N. Z Sanusi Department of Architecture, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Kuala Lumpur, Malaysia

Francesco Sasso Green Building R&D, Duesseldorf, Germany

Francesca Scalisi Department of Architettura, University of Palermo, Palermo, Italy

J. A. Scott Aston Business School, Aston University, Birmingham, UK

D.K. Serghides Department of Environmental Science and Technology, Cyprus University of Technology, Limassol, Cyprus

Despina K. Serghides Department of Environmental Science and Technology, Cyprus University of Technology, Limassol, Cyprus

Ehsan Shafiei School of Engineering and Natural Sciences, Environment and Natural Resources, University of Iceland, Reykjavik, Iceland

Li Shao Division Institute of Energy and Sustainable Development, University of Reading, Reading, UK

Teng Shao School of Architecture, Harbin Institute of Technology, Harbin, China

Wen Zhong Shen Department of Wind Energy, Technical University of Denmark, Kongens Lyngby, Denmark

Toru Shigemitsu Institute of Science and Technology, The University of Tokushima, Tokushima-city, Japan

Maryam Singery Department of Architecture, Tabriz Branch, Islamic Azad University, Tabriz, Iran

Hermanto Siregar Graduate School of Business Management, Bogor Agricultural University, Bogor, Indonesia

Shaun Slater School of Engineering, Robert Gordon University, Aberdeen, UK

K Sopian Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

Cesare Sposito Department of Architettura, University of Palermo, Palermo, Italy

Bernard H. Stark Faculty of Engineering, University of Bristol, Bristol, UK

M. Stathopoulos Soft Energy Applications and Environmental Protection Laboratory, Mechanical Engineering Department, Technological Educational Institute of Piraeus, Athens, Greece

Francesca Stazi Dipartimento di Ingegneria Civile, Edile e Architettura—Università Politecnica delle Marche, Ancona, Italy

Hlynur Stefansson School of Science and Engineering, Reykjavik University, Reykjavik, Iceland

Detlef Stolten Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, IEK-3: Electrochemical Process Engineering, Jülich, Germany

RWTH Aachen University, Aachen, Germany

Kazuyoshi Sumi Department of Marine Engineering, Marine Technical College, Hyogo, Japan

Erwin Susanto Sadirsan Bogor Agricultural University, Bogor, Indonesia

Donald Swift-Hook Kingston University, Woking, Surrey, UK

S. N. N. Syed Yahya Department of Architecture, University of Malaya, Kuala Lumpur, Malaysia

Chihiro Tanaka Graduate School of Advanced Technology and Science, The University of Tokushima, Tokushima-city, Japan

Sarah Tatum School of Engineering, Cardiff University, Cardiff, UK

Frederico F. Taves Tractebel Energia S.A. (GDF Suez), Florianópolis, Brazil

Javier Terrados Cepeda School of Architecture, University of Malaga, Málaga, Spain

Sant Tonio University of Malta, Msida, MSD, Malta

Evangelia Topriska Brunel University, Uxbridge, UK

Mridula Tripathi Department of Chemistry, C.M.P. Degree College, University of Allahabad, Allahabad, India

G. Tzanes Soft Energy Applications and Environmental Protection Laboratory, Mechanical Engineering Department, Technological Educational Institute of Piraeus, Athens, Greece

Ioana Udrea Faculty of Mechanical Engineering and Mechatronics, Thermodynamics Department, Polytechnic University of Bucharest, Bucharest, Romania

Herman Jacobus Vermaak Department of Electrical, Electronic and Computer Engineering, Central University of Technology, Free State, Bloemfontein, South Africa

Ana Vranjes Faculty of Mining and Geology, Department of Hydrogeology, University of Belgrade, Belgrade, Serbia

Rungrat Wattan Department of Physics, Solar Energy Research Laboratory, Silpakorn University, Nakhon Pathom, Thailand

Trevor Whittaker SPACE, Queen's University Belfast, Belfast, Northern Ireland

B.W. Williams Electronics and Electrical Engineering Department, Strathclyde University, Glasgow, Scotland, UK

Samuel J. Williamson Faculty of Engineering, University of Bristol, Bristol, UK

Earle Wilson University of Technology, Kingston, Jamaica

D. Wright Aston Business School, Aston University, Birmingham, UK

Jun Yao School of Engineering, University of Lincoln, Lincoln, UK

Yufeng Yao Department of Engineering Design and Mathematics, University of the West of England, Bristol, UK

Lee Young-Ho Division of Mechanical and Energy System Engineering, Korea Maritime and Ocean University, Busan, Korea

Kamil M. Yousif Dept of Environmental Sciences, Zakho University, Zakho, Iraq

Wei Yu Key Laboratory of Eco-environments in Three Gorges Reservoir Region, Ministry of Education, Chongqing University, Chongqing, China

National Centre for International Research of Low-Carbon and Green Buildings, Chongqing, China

D. Zafirakis Soft Energy Applications and Environmental Protection Laboratory, Mechanical Engineering Department, Technological Educational Institute of Piraeus, Athens, Greece

Wim Zeiler Faculty of the Built Environment, University of Technology Eindhoven, Eindhoven, The Netherlands

University of Technology Eindhoven, Eindhoven, Netherlands

Ming Zhang Key Laboratory of Eco-environments in Three Gorges Reservoir Region, Ministry of Education, Chongqing University, Chongqing, China

National Centre for International Research of Low-Carbon and Green Buildings, Chongqing, China

Xinyu Zhang School of Architecture, Harbin Institute of Technology, Harbin, China

Wei Zhao School of Architecture, Harbin Institute of Technology, Harbin, China

Wei Jun Zhu Department of Wind Energy, Technical University of Denmark, Kongens Lyngby, Denmark

Rima Zouagri Energetics Applied Physics Laboratory, Department of Material Physics, Faculty of Sciences, Hadj Lakhdar University, Batna, Algeria

http://www.springer.com/978-3-319-17776-2

Renewable Energy in the Service of Mankind Vol I
Selected Topics from the World Renewable Energy Congress
WREC 2014
Sayigh, A. (Ed.)
2015, XXIX, 985 p. 514 illus., 401 illus. in color.,
Hardcover
ISBN: 978-3-319-17776-2

Chapter 68
Earth Construction: The Mechanical Properties of *Adobe* with the Addition of *Laponite*

Francesca Scalisi and Cesare Sposito

Abstract The contribution describes testing of compression strength, flexural strength and abrasion resistance of *adobe* made up of soil, water and sand (AS), soil, water, sand and straw (ASP), soil, water, sand and laponite nanoparticles (ASN). Embodied energy in materials presents an increasingly high percentage of the energy spent in the whole life cycle of a building. The same applies for carbon dioxide (CO_2). Therefore, the development of new sustainable construction materials with lower embodied energy and lower CO_2 emissions is needed.

The use in construction of the brick made from soil, water and sand or straw, called *adobe*, boasts a millenary tradition and in recent years there has been renewed interest in a material readily available and ecofriendly. Earth is a building material that is able to act perfectly in balance with the environment: earth lends itself to achievements accessible to any manufacturing organization and is also a resource available in most geographical contexts. It allows one to manufacture products suited to pursue energy conservation and comfort in different climatic regions. The use of *adobe* presents: reduction of embodied energy and CO_2 at component level; improvement of insulation properties; reduction of the total costs compared to existing solutions.

Keywords Earth · Nanoparticles · Architecture · Low energy

Paragraphs with the initials F.S. by Francesca Scalisi; paragraphs with the initials C.S. by Cesare Sposito.

F. Scalisi (✉) · C. Sposito
Department of Architettura, University of Palermo, Palermo, Italy
e-mail: francesca.scalisi@unipa.it

C. Sposito
e-mail: cesare.sposito@unipa.it

A. Sayigh (ed.), *Renewable Energy in the Service of Mankind Vol I*,
DOI 10.1007/978-3-319-17777-9_68

68.1 Introduction

The construction sector represents one of the major consumers of energy, consequently emitting a great quantity of CO_2 into the atmosphere. This situation concerns both the consumption of energy required in the production phase of the materials to be utilized in construction and the consumption of energy in the actual deployment phase of the building. It is well-known that winter heating and summer cooling inside a building brings about an enormous consumption of energy.

In the field of construction the saving of energy needs to be shaped by the use of sustainable materials that will contribute to insulating the building adequately and reducing energy consumption.

The utilization of earth blocks in construction dates back over a thousand years and in the last few years there has been a renewed interest in this easily acquired and ecofriendly material.

Making earth blocks does not demand a great amount of energy. In fact, in contrast to bricks it does not require a baking stage, their being dried out simply in a natural way. It is precisely in the baking stage that ordinary bricks emit large quantities of CO_2; by building a house of 100 m^2 with earth blocks instead of bricks one avoids expelling 20 t of CO_2 into the atmosphere.

It is a safe and natural prime material available in great quantities in the natural world and is completely recyclable.

In the operational phase it enhances the comfort of the building and contributes to a saving of energy, since:

- It regulates the humidity because it can maintain a constant level of humidity in the atmosphere of around 50 %.
- It regulates temperature in the home; heat produced by man, from electrical appliances and lighting, on entering through windows is absorbed by the ground, which then restores it again when necessary (e.g. in the evening). This enhances home comfort and boosts energy saving considerably.
- It protects from high temperatures; thanks to its specific heat and substantial size, it prevents heat from entering. At night it cools, and in the morning, when temperatures rise, it once again absorbs a great quantity of heat, thus reducing the ambient temperature during the day.
- It protects from noise; it has excellent values as regards to acoustic cutbacks, since it is an "elastic" material and absorbs noise, by preventing it from passing through.
- It protects from electromagnetic pollution; 15 cm of earth cut out 99 % of electromagnetic waves, a value that is higher than that of all other building materials.
- It purifies the air; domestic odours are conveyed by water vapour. Earth, by absorbing water vapour, functions as a natural filter and purifies the air.
- It prevents condensation; precisely because it can absorb humidity, it prevents condensation from forming on walls (including interstitial ones).

Earth blocks may represent the material of the future because they can satisfy the increasingly important requisites of environmental sustainability, energy performance, positive energy balance, healthiness of abode, disposability. Therefore it becomes fundamental to improve the performance of this material, especially from the point of view of mechanical resistance, which is decidedly inferior to that of bricks. laponite, a synthetic layered silicate, at nanometric dimensions, represents a stabilizer compatible with earth, given the predominant presence of SiO_2, and can improve the mechanical resistance of earth blocks [1].

(F. S.)

68.2 Preparing Adobe

The sample realized is of the adobe type, an earth brick shaped by hand in a mould, without being compressed, and left to dry under natural conditions. The mixture used to produce traditional adobe is: soil and water with sand or straw as a stabilizer [2, 3]. The materials used to make the samples are: soil, sand, water, straw and laponite nanoparticles (Fig. 68.1). Soil was taken from the Roccasieli quarry, situated in the municipality of Motta S. Anastasia in Sicily. The sand utilized was lavic and of basaltic origin from Nicolosi in Sicily. The straw is from Nicolosi. The laponite RD is a synthetic layered silicate, supplied by Rockwood Additives Ltd. as a white powder and used without further purification. It is composed of rigid disk-shaped crystals with a well-defined thickness of 1 nm and a diameter of 25 nm.

In the first phase, the samples produced were of two types: the AS sample, made up of 31.54 % soil, 30 % sand and 38.46 % water; the ASP sample made up of 27.12 % soil, 30 % sand, 41.38 % water and 1.5 % straw (Fig. 68.2). The sizes of the samples were 40 × 40 × 160 mm, for the flexion and abrasion tests, and 50 × 50 × 50 mm for the compression test. The specimens were observed through the *scanning electron microscope* (*SEM*), which showed a graph of the elements and their distribution for each type of sample analyzed (Figs. 68.3, 68.4, 68.5).

(C. S.)

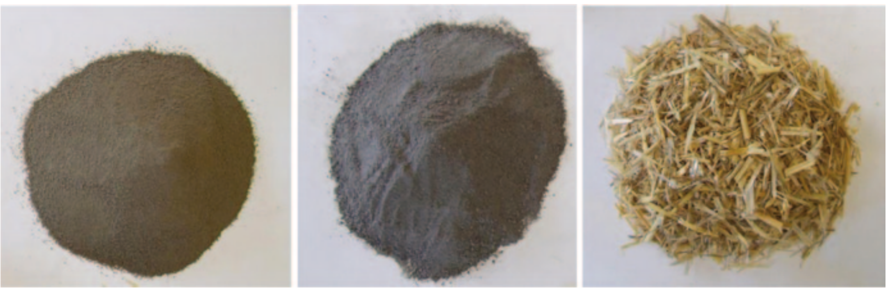

Fig. 68.1 The materials used to make the samples. From *left*: soil, sand and straw

Fig. 68.2 The samples: ASP (*left*) and AS (*right*)

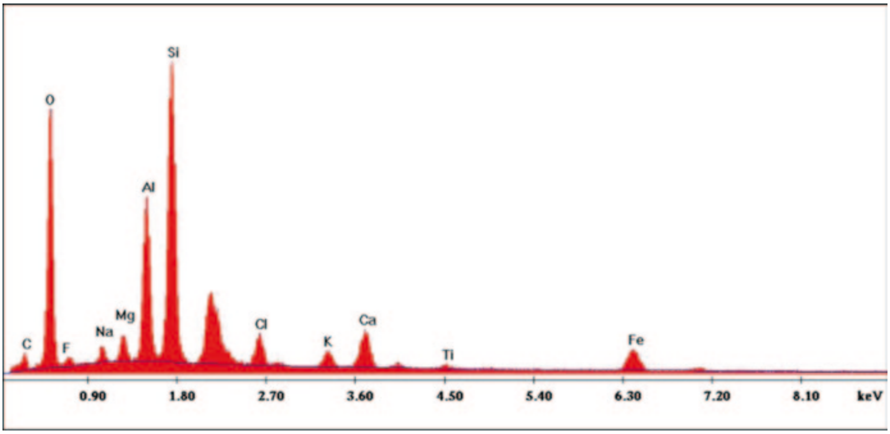

Fig. 68.3 SEM 100.000x chemical composition of AS sample

68.3 Testing of Compression Strength of the AS and ASP Samples

In the absence of regulations regarding earth bricks, for the administration of compression reference was made to the NORMA UNI EN 772–1:2011 the title being *Testing Methods For Masonry Elements—Part 1: Determining Compression Resistance*. Before carrying out the tests the samples were compacted to constant mass, at a temperature of 20 ± 2 °C and relative humidity of 65 ± 5 % [4–7]. The compression resistance demanded for an *adobe* is about 2 MPa. The samples made up of soil, water and sand (AS) showed an average compression resistance of 3.6 MPa, whilst those composed of soil, water, sand and straw (ASP) showed an average compression resistance of 2.8 MPa (Table 68.1; Fig. 68.6).

(F. S.)

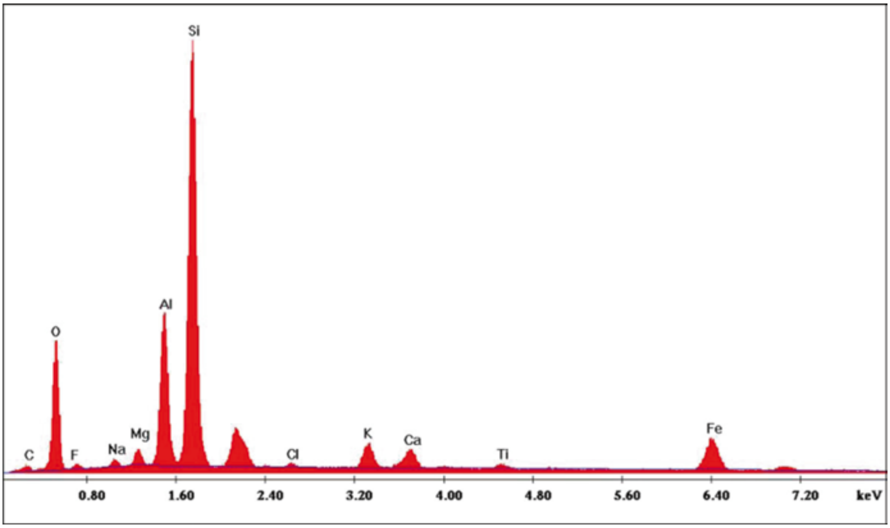

Fig. 68.4 SEM 100.000x chemical composition of ASP sample

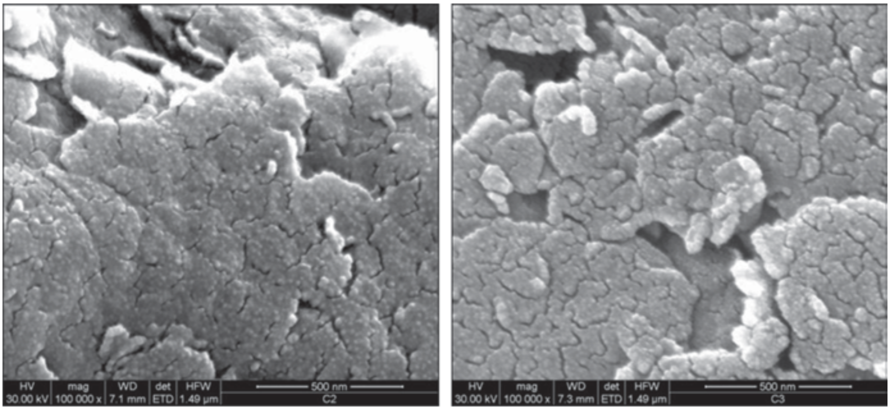

Fig. 68.5 SEM 100.000x of samples AS (*left*) and ASP (*right*)

Table 68.1 Test results of compression strength of the AS and ASP samples

Sample	Compression strength (MPa)	Sample	Compression strength (MPa)
AS/1	4.0	ASP/1	2.9
AS/2	3.0	ASP/2	2.7
AS/3	3.2	ASP/3	2.4
AS/4	3.4	ASP/4	2.7
AS/5	4.6	ASP/5	2.8
AS/6	3.4	ASP/6	3.0
Average compression strength 3.6 MPa		Average compression strength 2.8 MPa	

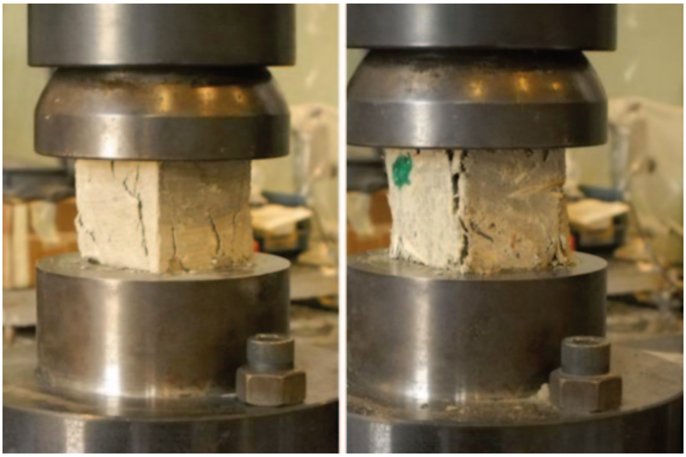

Fig. 68.6 The samples, AS (*left*) and ASP (*right*), to be tested for compression strength

68.4 Testing of Flexural Strength of the AS and ASP Samples

In the absence of regulations regarding earthen bricks, for the administration of the flexion tests, reference was made to the NORMA 12372:2007 with the title *Testing methods for natural stone—Determining flexion resistance under concentrated load.* Before carrying out the tests the samples were compacted to constant mass, at a temperature of 20 ± 2 °C and relative humidity of 65 ± 5 % [4–7]. The flexion resistance demanded for an *adobe* is about 0.4 MPa. The samples composed of soil, sand and water (AS) present an average flexion resistance of 1.7 MPa, whilst those composed of soil, sand, water and straw (ASP) present an average flexion resistance of 1.02 MPa (Table 68.2; Fig. 68.7).

(C. S.)

Table 68.2 Test results of flexural strength of the samples AS and ASP

Sample	Flexural strength (MPa)	Sample	Flexural strength (MPa)
AS/1	1.8	ASP/1	1.2
AS/2	1.8	ASP/2	0.9
AS/3	1.6	ASP/3	1.2
AS/4	1.6	ASP/4	0.9
AS/5	1.7	ASP/5	0.9
Average flexural strength 1.7 MPa		Average flexural strength 1.02 MPa	

Fig. 68.7 The ASP sample to be tested for flexural strength

68.5 Testing Abrasion Resistance of the AS and ASP Samples

The resistance-to-abrasion tests were carried out on three specimens for each typology, with the use of a metallic bristle brush. The evaluation of the test was carried out by quantifying the actual weight of the material removed, through the difference between the initial weight of each sample and the weight subsequent to the abrasive action. The procedure entailed the initial weighing of each sample using precision electronic scales and the subsequent rubbing of one side of the sample for one minute with a brush loaded with a weight of 3 kg; at the end of each test, the respective specimens were again weighed to determine the difference with the initial weight and, consequently, the amount of material removed. The AS samples registered a lower average weight for the material removed than that of the ASP, 2.96 g as against 3.93 g (Table 68.3).

(C. S.)

Table 68.3 Test results of abrasion resistance of the AS and ASP samples

Sample	Initial weight (g)	Final weight (g)	Amount of material removed (g)
AS/19	504.14	500.62	3.52
AS/26	502.00	498.68	3.32
AS/30	496.58	494.54	2.04
Average weight of material removed 2.96 g			
ASP/13	463.51	459.34	4.17
ASP/28	464.52	460.61	3.91
ASP/30	463.55	459.84	3.71
Average weight of material removed 3.93 g			

68.6 Testing of Compression Strength, Flexural Strength and Abrasion Resistance of ASN Samples

The tests carried out show how AS samples have greater resistance to compression, flexion and abrasion than the ASP samples. This is due to the presence of straw, which renders the mixture less compact. On the basis of these results, ASN samples were realized with the addition of a small amount of laponite. The ASN samples comprised 25 % sand, 38.46 % water, 31.54 % soil and 5 % laponite nanoparticles. The laponite nanoparticles and the ASN sample were observed through the SEM, which showed a graph of the elements and their distribution for each type of sample analyzed (Figs. 68.8, 68.9, 68.10). The ASN samples were subjected to compression, flexion and abrasion tests. The samples composed of soil, sand water and laponite nanoparticles (ASN) showed an average compression resistance of 4.7 MPa, an average flexion resistance of 2.42 MPa (Table 68.4) and an average weight for the material removed of 0.85 g (Table 68.5) (Fig. 68.11).

(F. S.)

68.7 Conclusions

The use of laponite nanoparticles in adobe bricks has brought an increase in compression, flexion and abrasion resistance when compared to traditional bricks. As regards resistance to compression, there was a 30 % increase over the AS samples,

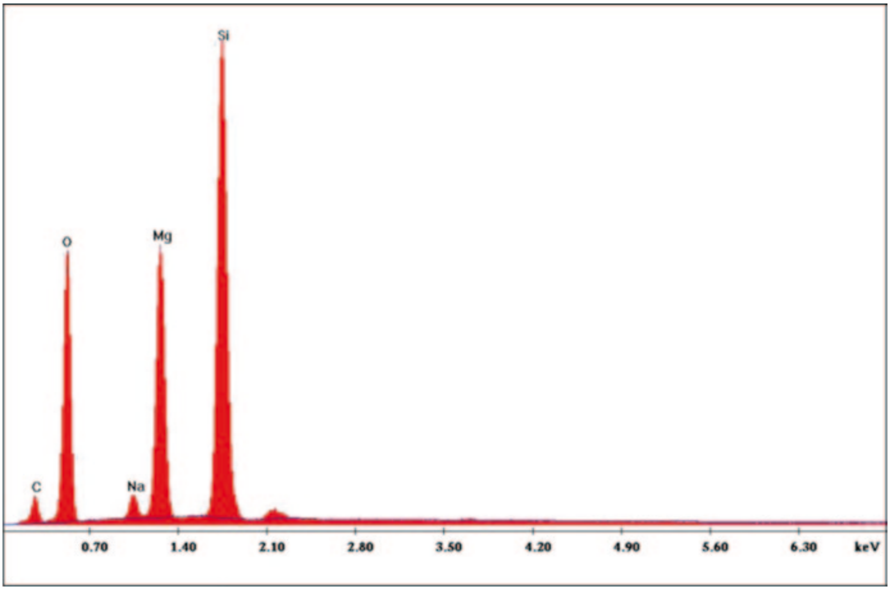

Fig. 68.8 SEM 100.000x chemical composition of laponite

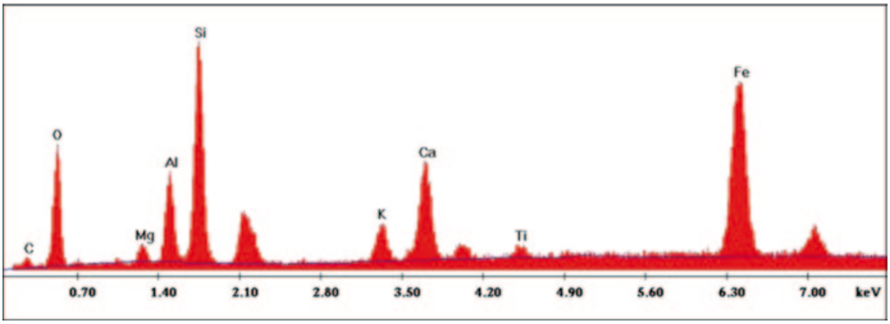

Fig. 68.9 SEM 100.000x chemical composition of ASN sample

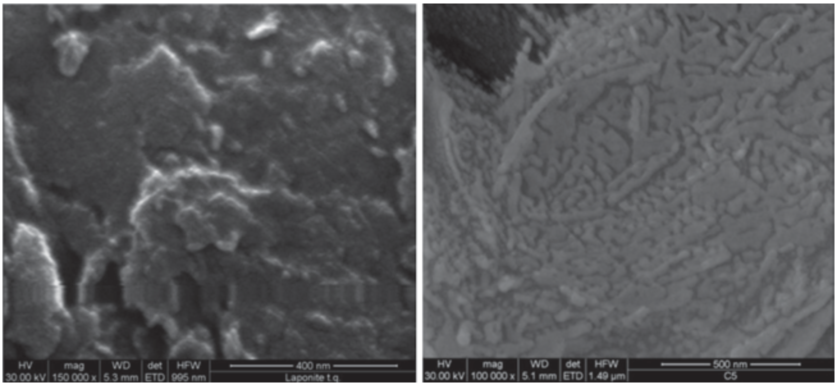

Fig. 68.10 SEM 150.000x of laponite (*left*) and SEM 100.000 of ASN sample (*right*)

Table 68.4 Test results of compression and flexural strength of the ASN samples

Sample	Compression strength (MPa)	Sample	Flexural strength (MPa)
ASN/1	4.1	ASN/1	1.9
ASN/2	5.0	ASN/2	2.2
ASN/3	4.4	ASN/3	2.3
ASN/4	4.7	ASN/4	2.4
ASN/5	5.3	ASN/5	2.8
ASN/6	4.7	Average flexural strength 2.42 MPa	
Average compression strength 4.7 MPa			

Table 68.5 Test results of abrasion resistance of the ASN samples

Sample	Initial weight (g)	Final weight (g)	Amount of material removed (g)
ASN/1	506.08	505.45	0.63
ASN/2	515.99	515.01	0.98
ASN/3	509.23	508.30	0.93
Average weight of material removed 0.85 g			

Fig. 68.11 The ASN sample to be tested for abrasion resistance

and 45 % over those made from soil, water, sand and straw (even though the latter also showed lower resistance than bricks made from earth, water and sand). As regards resistance to flexural strength, there was a 43 % increase over the AS samples and 60 % over those made from soil, water, sand and straw (even though the latter also showed lower resistance than bricks made from earth, water and sand). As for resistance to abrasion, the performance of the ASN samples was 3 times greater than the AS samples and 4 times greater than the ASP samples.

(F. S.)

References

1. Ashby MF, Ferreira PJ, Schodek DL (2009) Nanomaterials, nanotechnologies and design. Elsevier, Oxford
2. Fontaine L, Anger R (2009) Batir en terre. Du grain de sable à l'architecture. Belin, Paris
3. Rael R (2008) Earth architecture. Princeton Architectural Press, New York
4. Walker P (2002) The Australian earth building handbook, HB 195-2002. Standards Australia, Sydney
5. Morel JC, Pkla A, Walker P (2007) Compressive strength testing of compressed earth blocks. Constr Build Mater 21(2):303–309
6. Oliver M, Mesbah A, El Gharbi Z, Morel JC (1997) Mode opératoire pour la réalisation d'essais de résistance sur blocs de terre comprimée. Materials and Structures 30 (9): 515–517
7. Varum H, Costa A, Pereira H, Almeida J, Silveira D (2007) Mechanical characterization of adobe masonry walls. In: Proceedings of the 13th conference of sociedade portuguesa de materiais and IV international materials symposium—a materials science forum [CD-ROM], Porto, Portugal; April 1–4