# THE DURABILITY OF DISCONTINOUS ROOFING

**by Giuseppe Alaimo**

## 1 Introduction

The research carried out by the Unit of Palermo, “Planning and experimental evaluation methodologies of discontinuous roofing class durability”, becomes part in the more general picture of evaluation and control of the technological quality of complex products for the building and in particular of durability, fundamental to reach the quality in building (ISO 8402, UNI 10838), cause it regards maintenance in time of the performances possessed at the moment of the entrance in exercise and the modalities in which it decay during time.

For the research result fundamentals the normative contributions, in international field of CIB W80/RILEM 175 (Service Life Methodologies) and ISO TC59-Buildings Construction, with the ISO 15686 *Building and Constructed Assets Service Life Planning*, and in national field UNI11156 - 2006, “Evaluation of durability in buildings components” approved recently.

The methodology we have followed previews evaluation with two distinguished and complementary procedures of the two parameters of durability: *reliability* and *service life*.

Reliability is estimated through an object and functional analysis that permit a qualitative evaluation followed a comparative procedure lead between the elements of a catalogue of technical solutions of the class, which is considered out of system and with no intended use.

Service life is estimated through experimental tests on samples of technical elements exposed to natural agents and accelerated aging test in laboratory.

We choose sandwich panel, as the building components for our research.[1]

Experimental phase of research on samples of sandwich panel has been carried out through the following steps: characterization of parameters to controlled; analysis of initial performances; exposition in outdoor and monitoring of meteorological parameters of context; study of the relationship among agents-actions-effects; definition of the accelerated cycle; monitoring of characteristics properties during aging (in external or in laboratory); rescaling, elaboration of results and final conclusions on forecast models of in the time behaviour of panel (reference service life)

Experimental activity has been lead in various laboratories, this thing permit us to receive external contributions.[2]

To this research a remarkable contribution was given by Ing. Francesco Accurso, he has chosen that one in object, like argument of his thesis of doctorate.

[1] For this reason have been developed the contacts with AIPPEG (Associazione Italiana Produttori Pannelli ed Elementi Grecati) that kindly has offered its collaboration.

[2] For this I thank proff. Andrea Failla, Carlo Giaconia, Giovanni Rizzo, and their collaborators that have contributed with their important suggestions to the realization of such experiences that otherwise it would be problematic to develop.

## 2 The discontinuous roofing

The roof is a system constituted from more functional elements, each of ones contributes in different way to the development of the technological requirements of it and defines the performances that it must furnish (watertight, thermal insulation, mechanical strength, etc.).

The configuration of a discontinuous roofing results from different factors interdependent among them: functional factors; climatic; contextual; formal; specific of the seal.

The group of functional elements, every with its own physical and chemical characteristics and the mutual position, determines the behaviour of the roof.

### 2.1 Requirements of the discontinuous roofing

The main requirements that concern the class of the discontinuous roofing and particularly the coverage realized with metallic (UNI 10372) elements are: mechanical strength and stability, phase displacement and damping, thermal insulation, control of surface condensation, sound-proofing, watertight, resistance and reaction to the fire, stain resistance, resistance to frost and thermal shock, resistance to ultraviolet radiation, resistance to biological agents, resistance to weathering.

### 2.2 The repertoire

A repertoire of 24 technical solutions has been carried out (fig. 2.1), which includes also representative solutions of the local uses, as well as solutions "innovative" to study it and to compare its characters in comparison to those "traditional".

### 2.3 The assessment of the reliability

The method (Rejna, 1995), inserted in the norm UNI 11156 - 2006, based on the functional and technical analysis of the element, proceeds through the evaluation, with precise criterions of judgment, of the four components of the reliability (fig. 2.2):

- *functional reliability* that, through the functional analysis, it individualizes the distribution of the functions inside the solution, on which the degree of fatigue of the element depends during its operation;
- *executive reliability* that, through the technical analysis, verifies the degree of executive correspondence in comparison to the design intensions;
- *inherent reliability* that concerns the possible dimensional changes of the component in phase of exercise;
- *critical reliability* that considers physical-chemical compatibility between material adjacent of different nature constituent the technical solution.

### 2.4 The global reliability

The propensity to the global reliability (fig. 2.3) expresses in qualitative and comparative terms the degree of probability that the technical solutions have to last in time. Such values result from the arithmetic average among the correspondents values of reliability of the four components.

On the basis of the range of the fixed values, it is possible to perform with comparison: the design of a solution of given reliability, or to esteem the reliability of a given solution, different from those to the repertoire.

**Fig. 2.1 - Discontinuous roofing (DR): repertoire of technical solutions**

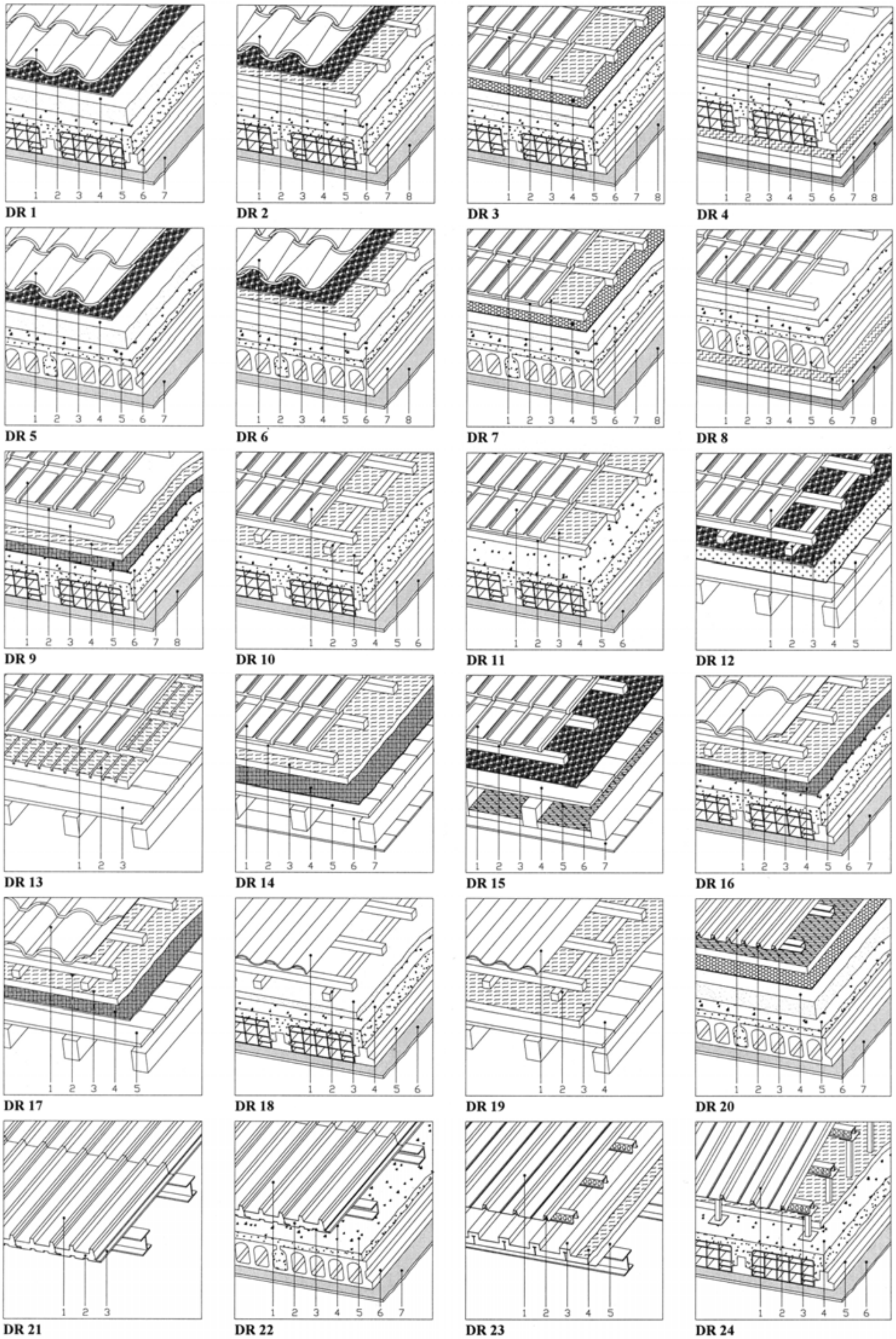


**Fig. 2.2 - Methodology for the assessment of reliability**

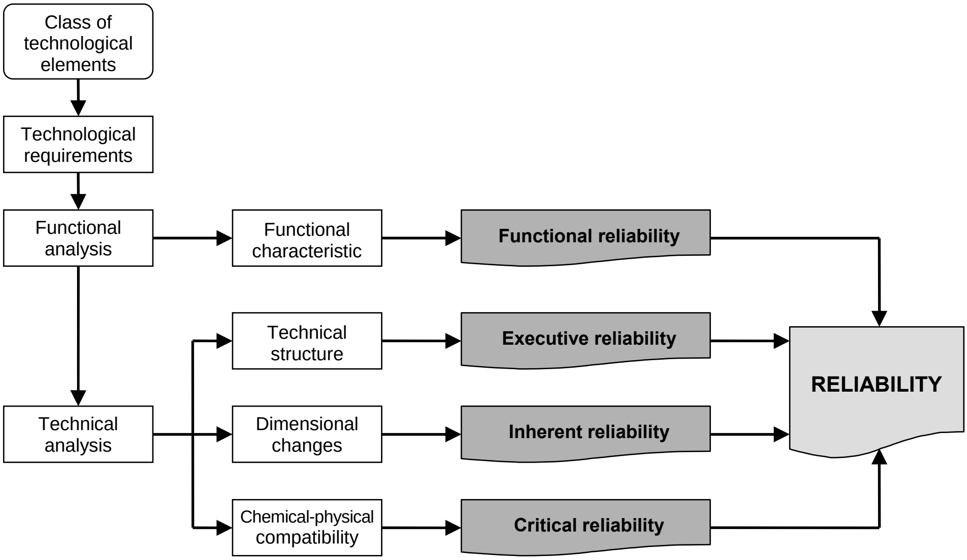
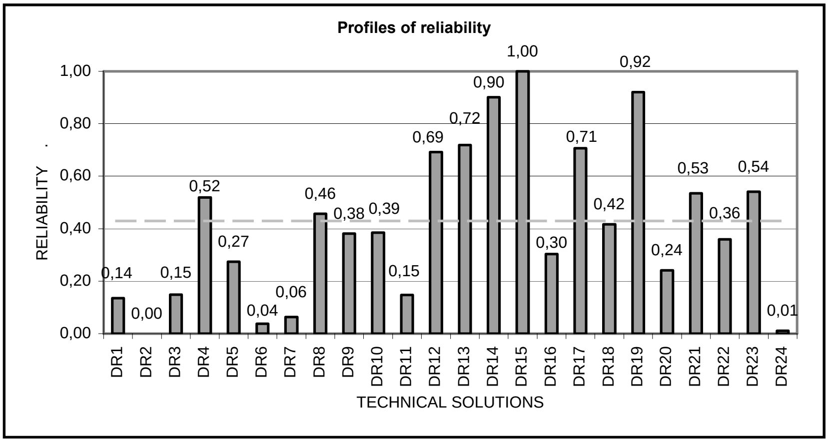



**Fig. 2.3 - Histograms of propensity to reliability of technical solutions**




## 3 Sandwich panel

As component to investigated experimentally, the sandwich panel has been chosen, which constitutes the seal of some technical solutions of the repertoire of which to the point 2.

### 3.1 The normative frame

The normative of reference for the discontinuous roofing and for the composite panels, in Italy, is represented by the UNI10372:2004.

For the composite panels mode with a core of expanded polyurethane and rigid skin the UNI10386:1998 is in force, that besides furnishing a classification of the panels, points out the principals requirements of it and the characteristics that the manufacturer must guarantee.

More recently to the European level, in order to get the acquisition of the CE label, there are been published:

- Technical Guides EOTA of the set ETAG 016 *Self-supporting Composite Lightweight Panels*, divided in four parts and finalized to the obtainment of the European Technical Approval of the composite panels.
- the harmonized European norm EN 14509 *Self supporting double skin metal faced insulating sandwich panels. Factory made products*. *Specifications*, by the CEN TC 128/SC 11, regarding particularly the insulating panels with metal skin (sandwich panels).

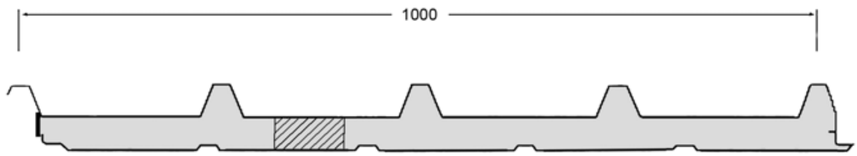
These last normative also furnish indications on the methods of test to evaluate the characteristics of the panel and particularly, the panel's durability.

### 3.2 The choice of the samples

One of the first ideas of the research is to study the influence that the different colour of the external surface can have on the performance decay of the sandwich panel and its parts, because of the aging.

The study has been conducted on samples of measures 100x100, 100x250, 100x1000 mm, cutted by standard panels as in fig. 3.1.

**Fig. 3.1 - Cross-section of whole panel and cutting of specimens**




The typical panel is constituted by a double metal skin of pre-painted galvanized steel and from an insulating core of polyurethane expanded (PUR) and thickness of 40 mm.

The colours of external surface are: White Grey and Siena Red.

**Tab. 3.1 - Characteristics of samples**

| | | Type 1 (roof) | Type 2 (wall) |
|---|---|---|---|
| **Outside metal skin** | Colour | Siena Red | White-Grey |
| | Side A | Pre-painted galvanized steel (0,45 mm) with polyester (25μ) | Pre-painted galvanized steel (0,45 mm) with polyester (25μ) |
| | Side B | Primer (5μ) | Primer (5μ) |
| **Foam** | | 40 mm PUR | 40 mm PUR |
| **Inside metal skin** | Colour | White-Grey | White-Grey |
| | Side A | Pre-painted galvanized steel (0,35 mm) with polyester (25μ) | Pre-painted galvanized steel (0,45 mm) with polyester (25μ) |
| | Side B | Primer (5μ) | Primer (5μ) |

## 3.3 The sequence: agents, actions, effects

Necessary methodological preamble to the experimental phase, is the definition of the reference frame of the agents - actions - effects[3] and therefore of the correspondents deteriorations that they can rise up in the components on the basis of the specific climatic context. This constitutes necessary preamble for the same definition of accelerated aging cycle, for it, only the natural agents will be considered.

## 3.4 The tests and the parameters

On the samples (new, aged in external and in laboratory) destructive and non-destructive tests have been conducted to check the following parameters and characteristics: aspect; weight; colour; thermo-physical characteristics (thermal conductivity and thermal resistance); mechanical (traction, shearing and bending) characteristics.

## 4 Natural aging

The samples of sandwich panel has been exposed in external in the month of March 2004, directed toward South and with slope of 30° in comparison (fig. 4.1a). Before the exposure, the edges of the specimens have been protected with a special polyurethane paint.

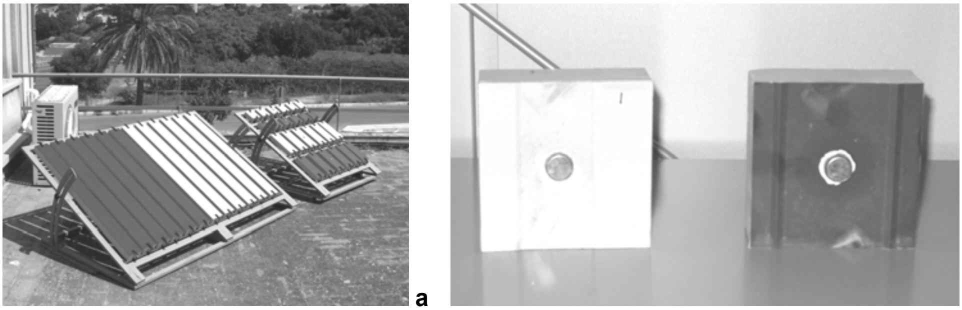
On some samples have been applied some programmable data-loggers (fig. 4.1b), in order to record the superficial temperatures reached (exposed and shade side) during the exposure.

The collected data, between March 2004 and March 2006, have allowed to determine the real course of the maximum, minimum and averages temperatures reached on the surface of the samples in Palermo with the different seasons of the year.

The definition of the characteristics and the parameters (type, intensity, length) of the climatic context constitutes fundamental preamble for the definition and the debugging of the accelerated aging cycle to use in the climatic chamber.

To such purpose the meteo-climatic stations nearest to the site of exposure of the specimens have been located and processed the data of the last ten years.

**Fig. 4.1 - The exposure in outdoor and temperature micro-loggers**



a b

[3] For the relative definitions it is sent to the glossary of CIB W86 *Building Pathology*.

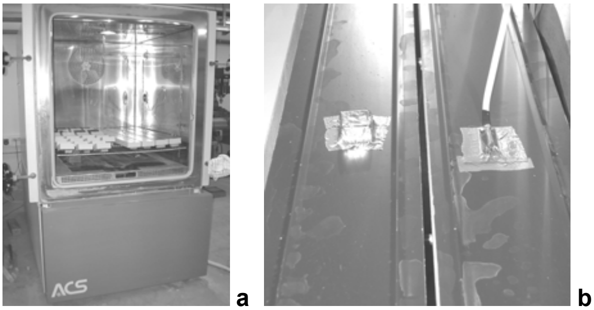
# 5 The accelerated aging

## 5.1 The cycle and its calibration

From the analysis of the collected data and from the course of the different climatic parameters, four representative seasons of the climatic context of Palermo city are recognized. And particularly: one "summer season" (dry heat); one "autumn season" (rain); one "winter season" (cold); one "spring season" (warm dampness).

For every season the characteristic values of the four principal parameters have been recognized: temperature, relative humidity, rain and solar radiation.

**Fig. 5.1 - Climatic chamber and temperature loggers**



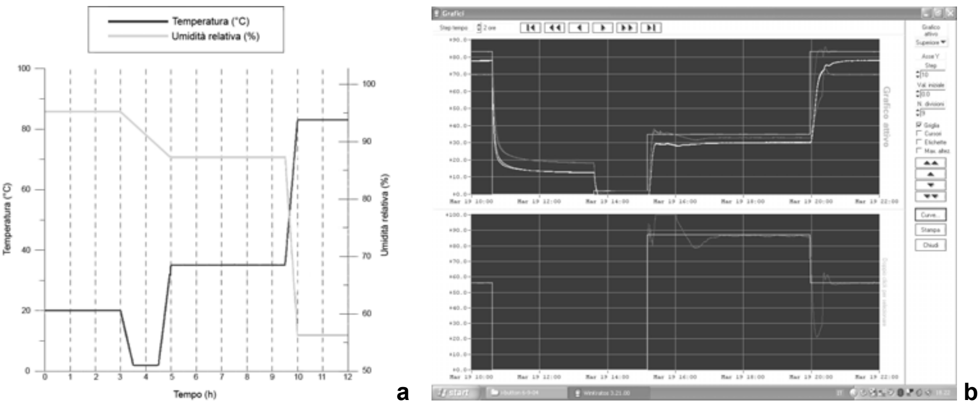

**Tab. 5.1 - Accelerated aging cycle structure**

| Phase | Parameter | | |
|---|---|---|---|
| | hour | T (°C) | RH (%) |
| Rain | 3,0 | - | - |
| Cold | 1,5 | 2 | - |
| Warm dampness | 5,0 | 35 | 87 |
| Dry heat | 2,5 | 83 | 56 |
| Total | 12 | | |

The phase of calibration of the cycle is necessary to validate the preliminary hypotheses and to verify the attainment of the conditions of requested solicitation on the samples (surface, inside, interface) in the climatic chamber (fig. 5.1).

At the end of this phase, kept account of other factors of influence like the slope of the samples, the superficial colour, the changes of temperature in the last decade and the normative existing on the thermal shock, we reach the following definitive cycle of accelerated aging (tab. 5.1, fig. 5.2a).

**Fig. 5.2 - Accelerated aging cycle: theoretical and experimental**



The climatic chamber simulates the principals climatic agents: rain, solar radiation, temperatures, humidity, through an unity of control that allows to program the sequence desired of the agents, the intensity and the duration.

Fixed the duration of the cycle of accelerated aging (12 hours), the length of the phases result consequently. It is necessary to remember that in the real cycle, between a phase and the following one there are transitory ones, in which temperature and humidity inside in the room before reaching the fixed values, employ a certain time. Nevertheless, for reasons for opportunity such transitions (of the general duration of around 2 h) have been inclusive in the general duration of the cycle (fig. 5.2b).

## 6 Tests and results

The tests, destructive (superficial aspect, weight, colour, thermal characteristics on the whole sample) and non-destructive (traction resistance, bending and shearing, thermal characteristics on the section of PUR), have concerned: the samples to the time zero; the external aged samples to 1 and 2 years; the artificially aged samples after 30, 60 and 120 cycles corresponding to 360, 720 and 1440 hours of accelerated aging.

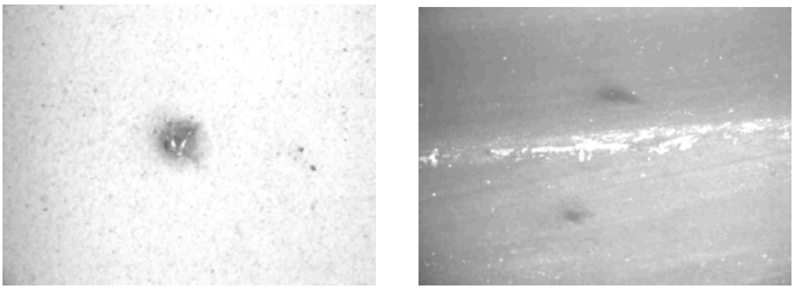
At the end of every phase of aging are been performed on the samples investigations turned to appraise the characteristics and parameters changes, in comparison to the time zero.

For every test have been made a least number of three specimens.

### 6.1 Superficial aspect

The analysis of the aspect doesn't show substantial differences among the aged samples in external to 24 months and those aged in laboratory up to 60 cycles. Superficial stain and punctual oxidations are primarily developed (fig. 6.1).

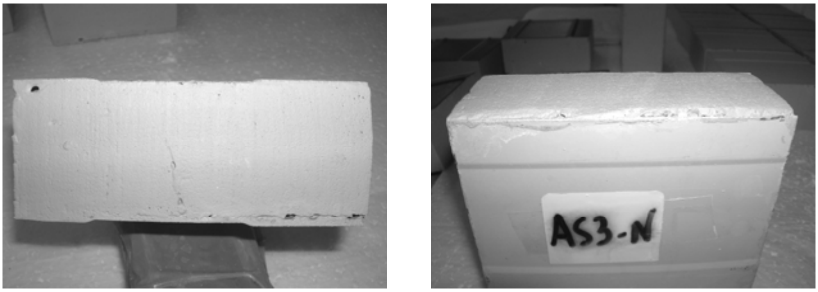
**Fig 6.1 - Defects observed with the microscope**



After 120 cycles the samples, also for their limited dimensions, have shown deformations of the form: increase of thickness of 1-2 mms and separations among metal skin and PUR along the edges that as expectation constitutes critical points where this degrade have departed despite the protective paint (fig. 6.2).

From the comparison among the seen effects a temporal correspondence can be hypothesized between the 60 cycles of accelerated aging and the 24 months of exposure in external.

Fig 6.2 - Detachment among PUR and metal skin



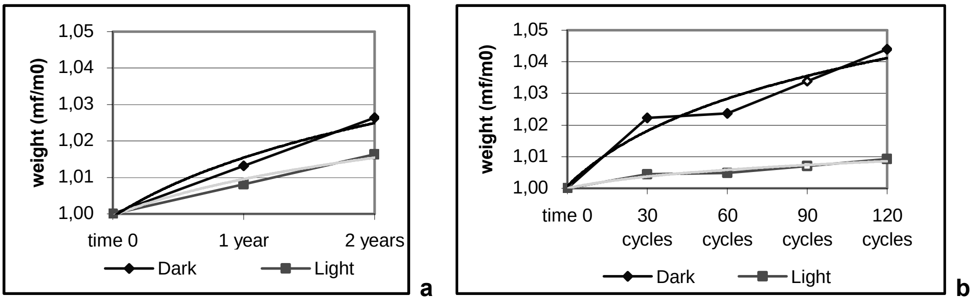

## 6.2 Weight

The sandwich panels in their complex can be considered impermeable. Nevertheless the vapour and, with it, water can migrate inside the insulating layer in polyurethane causing some dimensional variations that influence the shape, the weight and the same performances of the component.

From the comparison of the results among natural aging (fig. 6.3a) and accelerated aging (fig. 6.3b) a meaningful analogy emerges both qualitative and quantitative among the variations of weight of the samples, very limited and more for the dark samples.

Also under such aspect the effect of the first two years of aging in external it results entirely comparable with that caused by the first 60 cycles of aging in the climatic chamber.

Fig. 6.3 - Weight of aged in outdoor and laboratory specimens




## 6.3 Colour

It must be remembered that the effects of the different actions on the panel and on its part depend on the finish characteristics of the panel (paint), that in our case are of the standard type for normal environment without aggressive chemical substances.

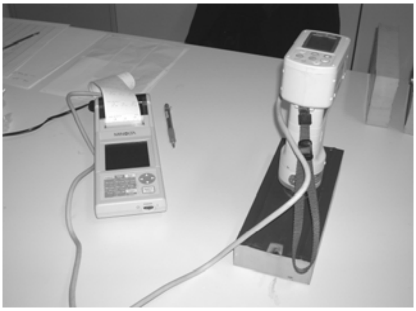
The results of the natural aging show a variation of colour more marked for the light samples (3 unities CIELAB) in comparison to those dark (1 unity).

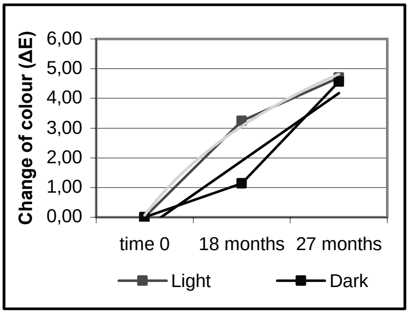
After 27 months such tendency remains and the variation ΔE* remains for both types of panel below the 5 unities[4], with a progressive yellowing of the light samples.

The two types of paint from the point of view of the variation of colour involve entirely in different way.

The aspect of the variation of the colour in comparison to original one, given the frequent use of the panels for external layers of buildings (roofs and/or walls), it isn't a negligible aspect since define the quality of the whole building. The maintenance of the project colour in the time is an aspect that deserves a suitable weight among the parameters to surely hold under control and a clearer normative in such sense it would serve to give a further and important contribution to the quality of the product.

**Fig. 6.4 - Specimen's changing colour (aging in outdoor)**

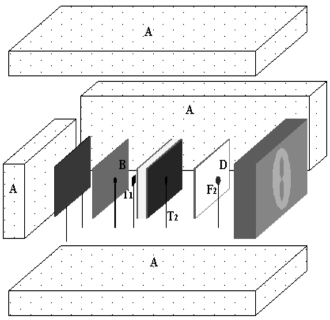





## 6.4 Thermo-physical characteristics

The used procedure is that for the measure of the thermal conductivity of building materials in stationary state, according to the norm UNI/CTI 7745 "Determination of the thermal conductivity with the method of the warm plate with mark ring".

**Fig. 6.5 - Apparatus for conductivity test**

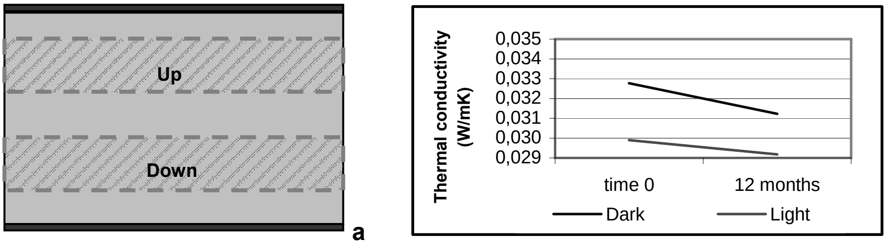



A - Polystyrene
B,D - Heat distribution plate
C - Specimen
E - Fan
T - Pt 100 sensor
F - Fluxmeter

[4] The norm foresees that after 5 years of exposure in external the variation of colour is inferior to 5 unities CIELAB, while the producers of pre-painted guarantee after 10 years in normal atmosphere an variation inferior to 8 unities Cielab.

The measures have been conducted both on the whole samples and on the polyurethane sections (using from the core of every samples two sections of the thickness of 10 mm) (fig. 6.6a), with the purpose to evaluate the influences of the external metallic elements and the interfaces with polyurethane.

**Fig. 6.6 - Sections of PUR and change of conductivity (natural aging)**



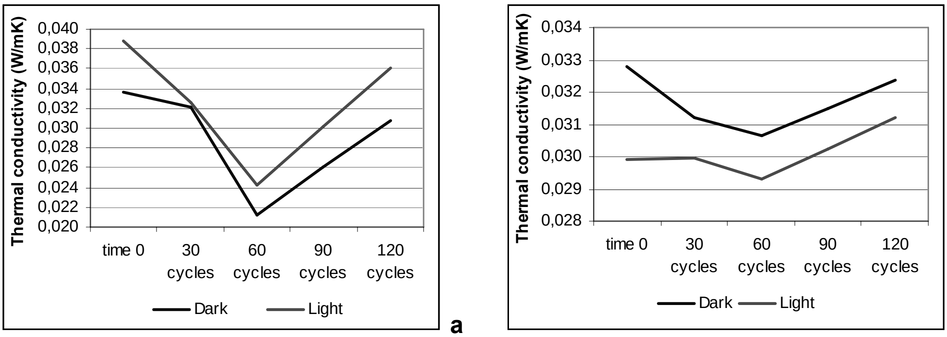

a b

Up to 24 months of external exposure the conductivity of the samples has substantially been constant, both in the whole samples and in the sections of PUR.

In general the thermal conductivity of the whole samples results greater than PUR sections, cause the lower contact resistance due to the cover sheets glued to the PUR.

The next tests will be conducted to three years of natural exposure.

**Fig. 6.7 - Change of conductivity in the whole sample and in the PUR sections (artificial aging)**




a b

There is a substantial constancy among the measures on the samples "Up" with those on the samples "Down".

The results of the tests in climatic chamber show an analogous behaviour from the qualitative point of view among the whole samples (fig. 6.7a) and the sections of PUR (fig. 6.7b) both for the samples White Grey and for those Siena Red.

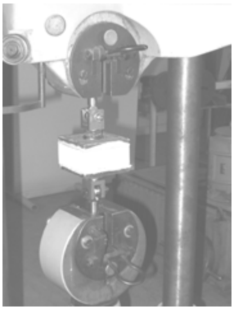
Also in this type of tests after the 60 cycles an inversion of tendency is observed with a substantial constancy of the thermal conductivity both in the first year of natural aging, and in the first 30 cycles of accelerated aging.

## 6.5 Mechanical strenght

### Tensile test

The test has the purpose to evaluate the tensile test of the polyurethanic foam and its adhesion to the metallic support (ETAG 016-1, UNI EN 1607, EN 14509) and show an improvement of the traction resistance up to 60 cycles, subsequently such tendency is reversed with the increase of cycles (fig. 6.7a).

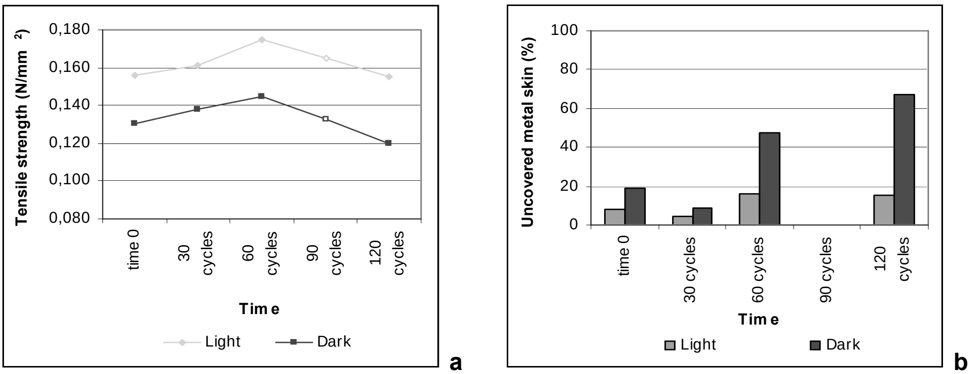
**Fig. 6.8 - Tensile test and type of failure (PUR)**



It seems us interesting to underline the relationship found among the tensile strength, the percentage of uncovered metal skin and the length of the aging. The aging causes in fact an increase of the percentage uncovered after the failure, effect more accented in the dark samples (fig. 6.7b).

From the comparison among the effects of the two types of aging, also in this type of tests a correspondence can be noticed among the effects of 60 cycles and those of 2 years of natural exposure.

**Fig. 6.9 - Tensile test and uncovered metal skin in tensile failure (artificial aging)**



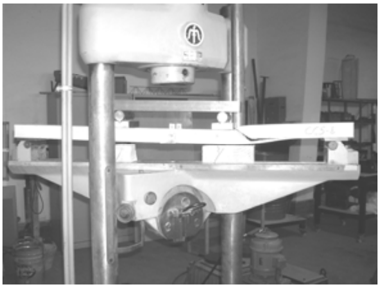

**Four-points bending test**

The test (EN 14509), conducted on samples of dimensions 1000x100 mm with increases of the load of 100 N, has brought to the construction of load-deflection curve and to the determination of the last shearing tension and the form of the foam.

It is observed, until here, a little diminution in time of the shearing strength of the panel, in fact, the ultimate shearing stress decreases both after around 30 months of natural aging and after 120 cycles of accelerated aging.

The other observed parameter, modulus of shearing of the foam, remains constant after the first 30 months external exposure, while it is increasing after 120 cycles of accelerated aging. This can be due to the polyurethane enbrittlement that, in the field of the elastic deformation, produces a lower flexibility of the samples.

**Fig. 6.10 - Four-points bending test**



**7 Conclusions and future developments**

The results, even partial, allow to express some considerations on the behaviour in time of the samples of sandwich panel investigated. Particularly is observed, that after two years of exposure in external the characteristics of the external covering (pre-painted metal skin) and the insulating polyurethane core are not so different from those that the component had in origin.

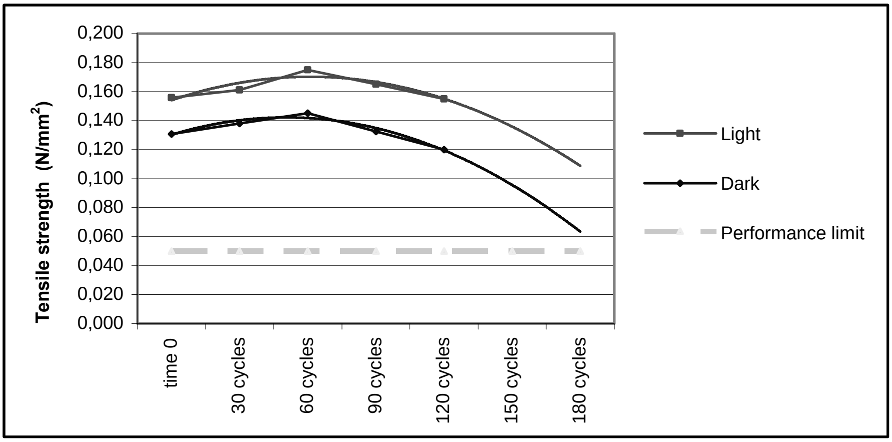
An analogous behaviour is observed, from the qualitative point of view, among tensile strength and thermal conductivity, the decrement of the characteristic up to 60 cycles and a following inversion of tendency with cycles.

Behaviour that somehow could be connected to the variations of weight and to the dimensional gymnastics of the elements of the panel (skin and core) favoured by phenomenons of diffusion and absorption of the vapour in the cellular structure of the polyurethane. For this reason the first measurements on artificial aged samples, point out a tendency to the increase of the resistance to the passage of vapour after the first 30 cycles.

The colour, that deserves more attention from the normative point of view, is the characteristic that has suffered the greatest variations among the observed ones. The light samples has variations of colour ($\Delta E$) greater than the dark, both with the natural and accelerated aging, nevertheless the behaviour in the two types of samples appears different. On those light an increasing course of $\Delta E$ is had with the aging, while in those dark the maximum variation is had after 30 cycles and subsequently such value decreases.

As it regards the end of service life of the component, according to the EN 14509 it's achieved when the value of tensile strength is less than 0,050 $N/mm^2$, as shown from the extrapolation of the diagram of fig. 7.1.

**Fig. 7.1 - Specimen's mechanical strength**




It will be useful continue to check the course of the thermal conductivity of the samples exposed in external to assume new elements on the role of the skin-core interface and on the variability of the insulating property. The study could evidence properties of the aged polymer and the gas contained inside the cells to substain an explanation to the improvement of the characteristics (tensile strength, thermal conductivity) measured in the initial phase of the panel's aging.

## 8 References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