Degradation of Glass Mineral Wool Insulation after 25 Years in Masonry Cavity Walls

Francesca Tittarelli, Francesca Stazi, Giacomo Politi, Costanzo di Perna, and Placido Munafò

***Abstract*—**An experimental study was carried out on glass wool insulation extracted from the cavity of vertical envelope of buildings constructed in the 1980s to evaluate the insulation conservation state after 25 years. Laboratory tests on insulation samples were carried out to assess any changes of the morphological, chemical, physical and thermal properties of the material. The results show that in glass mineral wool insulation, the glass fibers and the binder were affected by a degradation process thus increasing both water absorption and thermal conductivity.

***Keywords*—**Glass wool, thermal insulation material, durability, hydro-thermal performance.

I. Introduction

THE recent 2012/27/UE Directives for the promotion of the energy efficiency in Europe have underlined the importance of the renovation of the existing building stock since it represents the biggest potential sector for energy savings.

In order to identify the most suitable retrofit intervention on the existing low-insulated buildings to achieve the new levels of thermal resistance, it is important to investigate the state of conservation and the actual performance of the existing insulating materials after a service life of 20–30 years. Moreover, it is also necessary to assess the durability of the insulation materials identifying typical degradation phenomena in order to address the choice of suitable insulation material for new constructions.

In recent years some experimental studies have been carried out on the hydro-thermal performance of new fibrous insulation materials. In 2004, Ya Gnipet al. [1] conducted laboratory analysis for the determination of the adsorption isotherm of several insulation materials. In 2005, Achchaq et al. [2] studied through several laboratory tests the, morphological and thermo-physical proprieties of two new panel of glass wool. In 2006, Jirickovaet al. [3] determined the hydro-thermal behavior of two new hydrophilic mineral wool. In 2007, the same research group [4] analyzed the hydro-thermal performances of two typologies of wall with an interior thermal layer of hydrophilic mineral wool through laboratory measuring tools. In the same year, Björk et al. [5] compared the hydro-thermal characteristics of glass wool, melamine foam and corrugated sheets of cellulose plastic at different temperature and moisture conditions. Most recently, the moisture condensation in fibrous insulation materials with various densities under different levels of moisture content using appositely designed moisturizing devices has been analyzed [6, 7].

Very few studies involved an in situ monitoring of the performance of insulation layers in a 20-30 years old social house with energy simulations and comparing different retrofit interventions [8, 9].

The present study is focused on the evaluation by laboratory tests of the chemical, physical and morphological properties of glass wool insulation material after 25 years inside the cavity of an external wall in order to point out a possible deterioration.

II. Experimental

A. Materials

Cylindrical samples of glass wool were extracted from the walls of three case studies and compared with samples of new glass wool with similar characteristics as a reference. Table 1 shows the characteristics of the samples.

The samples with the name C1–C3 were extracted from a residential building erected in 1988 located in the city of Cingoli in a hilly region of the central Italy (about 600 m on sea-level) characterized by hot-summer Mediterranean climate.

The samples named MSG and M were extracted respectively from the case study of Monte San Giusto and Monte-Cosaro, near the city of Cingoli.

The exterior vertical envelopes of the three building are made up of hollow wall brick masonry with interposed insulation layer that is the most commonly used type of wall in the buildings of the 1970s and 1980s in central Italy. However, the central cavity in the building of Cingoli is wider than

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the others and the external part of the wall is made up of solid bricks while in the other two cases it is realized with perforated bricks and plaster.

The samples named N1, N2, N3, N4 were extracted from a new panel of glass wool characterized by different values of thermal conductivity.

TABLE I
INSULATION MATERIALS

Sample	λ declared (W/mK)
C1	0.043
C2	0.043
C3	0.043
MSG1	0.036
M1	0.036
N1	0.045
N2	0.045
N3	0.033
N4	0.033

B. Apparent Density

Apparent Density was obtained by calculating the ratio between mass and volume of samples according to UNI EN 1602.

C. Water Vapor Transmission

According to UNI EN ISO 12572, samples were sealed to the open side of a test cup containing an aqueous saturated solution of KNO_3 able to ensure inside the cup a RH = 93 ± 3% when the system is placed into a controlled test chamber at T = 23 ± 0.5◦C and RH = 50 ± 3%. Periodic weightings of the system were carried out.

D. Hygroscopic Sorption

The hygroscopic sorption curve was determined according to UNI EN ISO 12571. Sample were placed in different environments at constant temperature (T = 20 ± 0.5◦C) and different relative humidity values obtained by using several aqueous saturated solutions: $MgCl_2$ RH = 33 ± 3%, $Mg(NO_3)_2$ RH = 54 ± 3%, NaCl RH = 75 ± 3%, KNO_3 RH = 95 ± 3%. After achieving the equilibrium, in each environment, the sample weight was measured and reported in a diagram as a function of the relative humidity values.

E. Moisture Content

Moisture content was measured by calculating the ratio between the sample mass before and after drying in a thermostatic oven, according to UNI EN ISO 12570.

F. Thermal Analysis:

Samples were chemical characterized by Thermo-Gravimetric Analysis (TG) and Differential Thermal Analysis (DTA) in the temperature range 30–1000◦C with a temperature increase rate of 10°C/min.

G. Morphological Analysis:

The samples were observed under scanning electron microscope (SEM) equipped with EDAX probe (Energy Dispersive X-ray Analysis) for the elemental analysis of materials. Before SEM observations, small pieces, about 1 cm^3 in size, were extracted from specimens and covered with graphite.

H. Thermal Conductivity:

Thermal conductivity was measured with a device based on the heat flow meter method (according to UNI EN 12664) keeping the sample in stationary conditions. During the test, the specimen is placed between a hot plate (20◦C) and a cold plate (5◦C) in order to keep a constant temperature gradient through the specimen. The surface temperature and the heat flow at the center of the samples were measured for 24 h.

III. RESULTS

A. Apparent Density

For each sample, the apparent density was measured and for samples of the same type the relative averaged value was calculated (Table 2). The average apparent density for all the extracted samples is 12 kg/m^3. For the new samples N1 and N2 is 17 $kg/m^3$and for the new samples N3 and N4 is 28 kg/m^3. By comparing the values obtained by extracted samples with those obtained by original certified value of the same material, the apparent density is increased of about 2.5%. Considering the test accuracy, the apparent density remained constant in time. Thus, the glass wool did not change significantly its compaction degree.

TABLE II
APPARENT DENSITY

Sample	Apparent density (Kg/m^3)
Degraded samples	12
N1-N2	17
N3-N4	28

B. Water Vapor Transmission

Table 3 shows the hygroscopic resistance factor calculated according to the reference standards. The hygroscopic resistance factor is similar for all the samples so the materials did not change water vapor transmission properties with time. These results confirm what was achieved in Section A. Apparent Density: the inner porosity distribution, related to the compaction degree, did not change during the service life.

TABLE III
HYGROSCOPIC RESISTANCE FACTOR μ

Sample	μ
M1	1.49
C3	1.44
N1	1.37
N3	1.51

C. Hygroscopic Sorption

For each RH, the old glass wool sample (C3) has a water sorption at least two times higher than that of the new samples N1 and N3. The differences increase with the increase of the environmental relative humidity (Fig. 1).

All new samples have similar values of hygroscopic sorption and this guarantees a good repeatability of results. Moreover, the percentage of humidity in new samples was

always below of <1%, regardless the RH of environment.

In order to achieve good shape stability, during the manufacturing process, glass wool fibers are mixed with an organic binder based on a phenol-formaldehyde thermo resin, at the dosage of 3–9% by weight, and with about 1% by weight of a hydrophobic agent based on silicones. These admixtures permitted to decrease the already low hygroscopic sorption of glass fibers in order to increase the insulation performance and the durability.

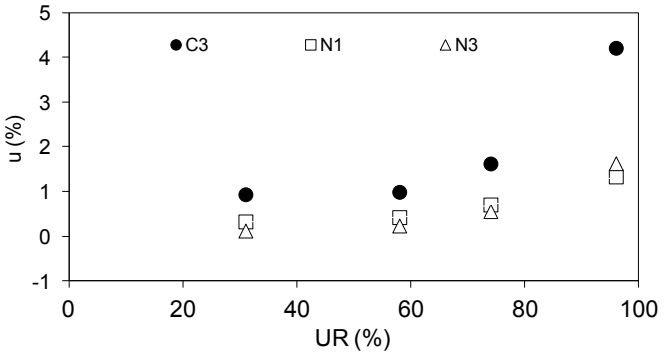

Fig. 1 Hygroscopic sorption curves: comparison between the new samples (N1 and N3) and aged sample (C3).

The greater hygroscopic sorption of the old sample might be caused by a partial de-polymerization for hydrolysis of the organic resin caused by the presence of moisture; this process caused the formation of –OH groups leading to a decrease of the material hydrophobicity (Fig. 2).

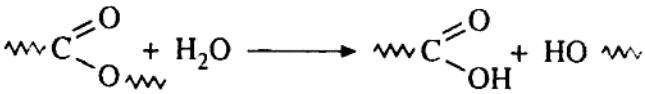

Fig. 2 Reaction of de-polymerization by hydrolysis of the polymeric binder of glass wool.

D. Moisture Content

Table 4 reports the initial water content of samples. MSG1 sample has the higher moisture content with a value of about 6%. M1 have a moisture content of about 2%. The study case C has an average value of 2%.

Generally, the moisture content in the glass wool is very low (less of 0.5%) due to the presence of the binder and the hydrophobic treatment as described in Section C Hygroscopic Sorption. The high values of moisture content measured in the old samples might have been caused by the partial degradation of the organic surface treatments that decreased the hydrophobicity of the materials.

TABLE IV
MOISTURE CONTENT

Sample	u (kg/kg)
C1	0.024
C2	0.013
MSG1	0.059
M1	0.018

E. Thermal Analysis

The thermal behaviors of an extracted sample (C3) and a new sample (N3) in the temperature range from 30◦C to 1000◦C are compared in Figs. 3 and 4. Fig. 3 shows both the curves of weight loss (TG) and the corresponding derivate curves (DTG) in order to outline the maximum decomposition temperatures, corresponding to inflection points in the TG curve, and to peaks in DTG.

The weight loss between 0◦C and 150◦C, corresponding to an endothermic process as revealed by DTA (Fig. 4), was caused by the water evaporation presented in the samples corresponding to 0.7% of the weight of the old sample and to 0.4% of the new one. Before the tests, the samples were treated in an environment with T = 23 ± 2◦C and RH = 60 ± 3%. These results are comparable with those obtained by the hygroscopic sorption curves.

The weight loss carried out from the TG until 600◦C is related to an exothermic process due to the combustion of the organic components (binder and hydrophobic agent) as observed from DTA. Their quantity is 8% of the weight in the extracted sample and 6% of the weight in the new sample. The comparison between the maximum temperatures of decomposition (the exothermal peaks in DTA) shows that the extracted sample has a slightly less thermal stability because it began to fire before the other sample.

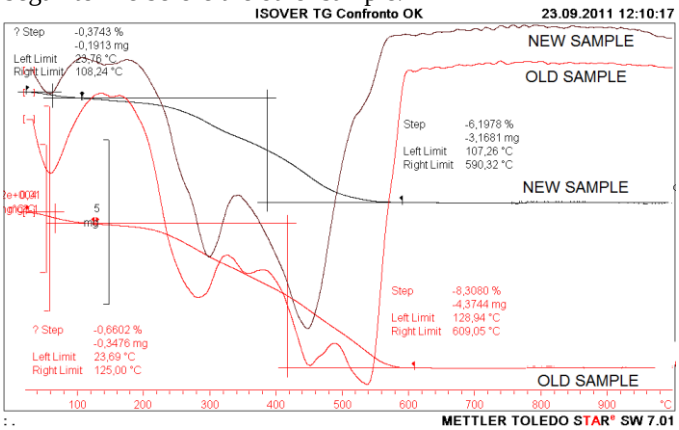

Fig. 3 Results of the TG analysis: comparison between the new sample (upper lines) and the old sample (bottom lines).

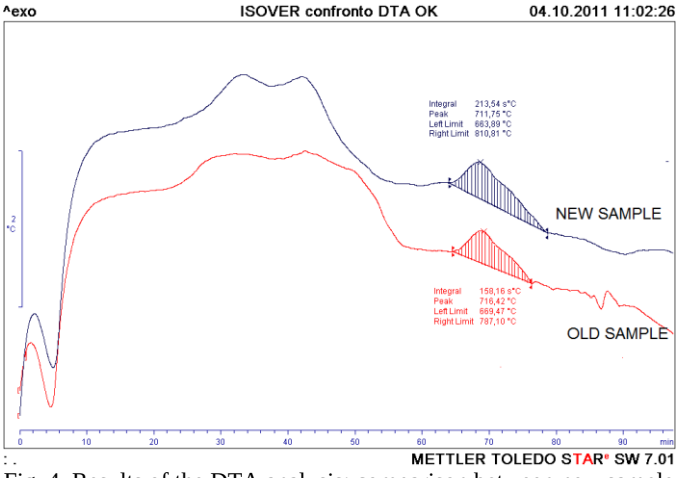

Fig. 4. Results of the DTA analysis: comparison between new sample and old sample.

Finally, Fig. 4 shows an exothermal transformation after 600◦C (hatched area) not related with a weight variation (Fig. 3); it is a change of phase due to the crystallization of the glass fibers before melting. The entity of crystallization of the extracted sample is about 26% lower than that of the new sample. This observation addresses that the glass wool after a service life of 25 years crystallized partially; the crystallization of the glass wool is a degradation process that makes glass fibers more fragile and pulverized.

F. Morphological Analysis

Fig. 5 shows the visual observation of the tested samples; the extracted sample (C3, on the right) has a darker yellow coloration than the new one (N3 on the left).

The morphological analysis of samples underlined a continuous, homogeneous and compact covering of the binder on the surface of the new glass fibers (Fig. 6).

On the other hand, on the extracted sample fibers, the covering seems inhomogeneous, discontinuous and with a diffuse excoriation of the binder (Fig. 7). As explained previously, the polymeric covering has undergone a process of partial de-polymerization by hydrolysis due to the moisture. The de-polymerization causes the formation of shorter polymeric chains with oxide groups that both decrease the hydrophobic of the covering and recombine the binder molecules in a new net causing a covering more stiff and fragile that tends to split itself from the fibers.

Table V shows the results of EDAX analysis carried out on fibers and binders evidencing not significant differences in the elemental composition between old and new sample. Generally, glass wool is composed by 65% of quartz sand/old glass, 14% soda, 7% dolomite,4% feldspar and 4% limestone. Obviously, in the analyzed fibers Si is the main element (≈60), followed by Ca (≈15%), Na (≈10%), Mg and Al (≈3%), K and Cl (≈1%). In the binder, about 20% of sulphur, derived from Na_2SO_4 used in the melting process.

Fig. 5 Visual observation of a new sample (N3, on the left) and an old aged sample (C3, on the right)

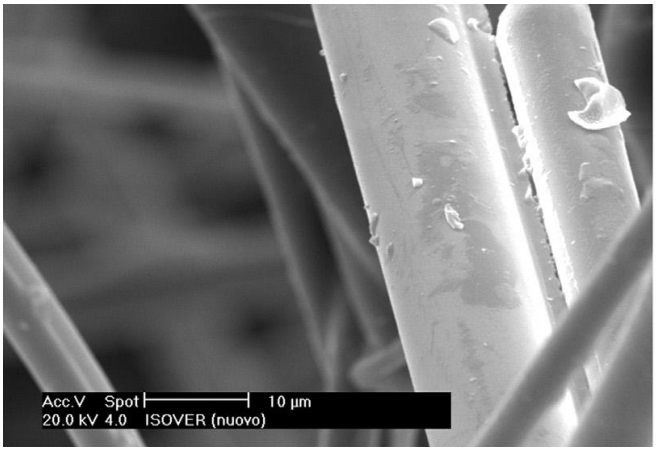

Fig. 6. Morphology of fibers of the new sample (N3)

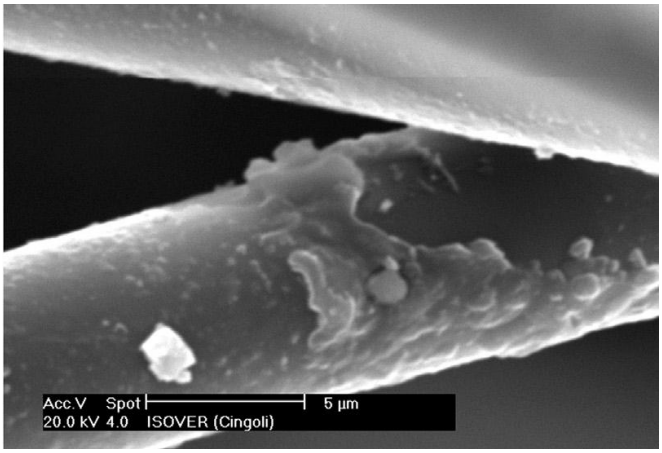

Fig. 7. Morphology of the fibers of aged sample (C3)

TABLE V
RESULTS OF EDAX ANALYSIS

Sample	Si %	S %	Cl %	K %	Ca %	Na %	Mg %	Al %
N3 Fiber	64	2	1	2	16	9	3	3
C3 Fiber	67	-	-	1	12	11	3	6
N3 Binder	40	30	1	1	9	10	3	6
C3 Binder	42	19	7	1	10	13	3	5

G. Thermal Conductivity

Table VI compares the values of thermal conductivity measured in laboratory for new and the extracted samples and the values declared by the producers.

TABLE VI
DECLARED AND MEASURED THERMAL CONDUCTIVITIES

Sample	λ declared (W/mK)	λ measured (W/mK)
C1	0.043	0.047
M1	0.043	0.049
N1	0.045	0.044
N3	0.033	0.034

Comparing the measured and declared values for the old samples (C1 and M1) an average decrease of thermal conductivity of 12% is observed. This reduction of performance could be related to the greater moisture content in the extracted samples due to the higher water absorption of the material caused by the partial degradation of the organic binder (Fig. 2).

IV. CONCLUSION

An experimental study was carried out on aged glass wool insulation extracted from the inner cavity of the vertical external wall of three buildings erected 25 years ago with hollow wall brick masonry envelopes to investigate the effect of aging on the chemical, physical and morphological properties of the material.

The obtained results show that the glass wool insulation during its service life has not shown sensible variations of the compaction degree keeping the same apparent mass and vapor permeability.

The glass wool shows a partial crystallization process of the glass fibers and, as a consequence, it suffered stiffening with increased susceptibility to pulverization.

The glass wool shows degradation of the polymeric binder that caused the decrease of the hydrophobicity of the material with a greater water sorption at the same environmental moisture.

The decreased hydrophobicity of the glass wool is the main cause of the about 12% increase of the average thermal conductivity, as verified from the laboratory tests;

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