FORMULATION OF LIME MORTARS BASED ON NATURAL FIBERS AND WASTE MATERIALS FOR MORE SUSTAINABLE BUILDINGS

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Abstract

Nowadays sustainability is one of the main concept in building construction, both considering energy saving buildings and life cycle assessment of building materials. According to these considerations, in this work the use of recycled and waste materials to produce a binder and the use of a natural fiber as reinforcement are investigated to obtain a sustainable mortar. Particularly, lime is obtained by kilning waste marble slurry from marbles quarries in western Sicily; pozzolanic aggregate is obtained by grinding glass powder from urban waste collection; natural fibers come from a widespread grass: *Ampelodesmos Mauritanicus* also known as diss. Scanning electron microscopy and helium picnometry have been performed to characterize diss fibers. Samples with different fibers volume percentage have been prepared and subjected to three-point bending and compression tests, in order to verify the modification of resistance related to the presence of fibers; moreover, capillary uptake and thermal conductivity have been evaluated.The results show a great influence of fibers' percentage on both mechanical and environmental properties of mortars, resulting in lowering of mechanical resistance and thermal conductivity.

Keywords:

Recycled glass; Marble slurry; Ampelodesmos mauritanicus; Sustainable mortars

1 INTRODUCTION

Building sustainability is strictly related to energy saving in materials, design, building techniques and, particularly with respect to existing buildings, to improvement of energy effectiveness of buildings [Gaspari, 2008].

Buildings are responsible for the consumption of half of natural resources used by human beings, almost 40% of energy consumption and production of 25% of waste materials, so that every materials designed for building engineering should be formulated in order to reduce its Life Cycle Assessment (LCA), considering all the environmental effects in the life of a product, from raw materials extraction to waste collection [Berti, 2016]. According to LCA a product could be labelled environmentally sustainable if it comes at least partially from recycled or renewable sources [Cumo, 2013].

Several new materials have been developed in the last years starting from renewable or recycled materials and aim of this experimental work is the formulation of a mortar produced starting from waste materials.

Particularly natural fibers, commonly used in ancient mortars [Stefanidou, 2016], nowadays are used to reduce the carbon footprint of building materials [Amziane, 2016] offering interesting improvement of the behaviour of both fresh [Amziane, 2016; Boghossian, 2008] and hardened concrete or lime mortars [Ardanuy, 2015].

Proposed mortars are characterized according to Italian Uni standard test in order to verify mechanical and thermal properties to assess their performance.

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2 MATERIALS AND METHODS

2.1 Materials

As the aim of this work is the formulation of an environmentally sustainable mortar, recycled materials have been used for the production of a binder with lower energy and raw materials consumption coupled with the use of natural fibers from widespread plant associated with the risk of fire.

Particularly in this work marble slurry, river sand, glass powder and diss fibers have been used.

Marble slurry comes from sawing and polishing industries associated with marble quarries in Custonaci, the main sicilian site for extraction of a compact, polishable limestone called "Perlato di Sicilia" a fine mesozoic sedimentary limestone referred to as marble for its technological characteristics. Marble slurry is classified as an industrial waste materials, according to

Italian laws, and is often disposed as landfill, with some environmental risks [Rizzo, 2008]. In this work marble slurry was used to produce air hardening lime by kilning and slaking.

A commercial siliceous river sand was used as aggregate.

Cullet coming from urban waste collection in Palermo and supplied by Sarco s.r.l. was used to produce a fine powder that could act as pozzolanic aggregate. Glass powder is studied in literature as a supplementary pozzolanic material, to be used particularly in concrete production [Shi, 2007; Shekhawat, 2014] or in cement mortars [Idir, 2008].

Diss fibers have been used as reinforcement. Diss is the common name of *Ampelodesmos Mauritanicus*, a spontaneous perennial grass very common in the Mediterranean area belonging to the grass subfamily Pooideae. It grows on dry and sandy soil and it's widespread in Sicily, resilient to harvest and fire.

Finally Diss fibers have been burnt in open air in order to obtain diss ashes to verify their pozzolanic behavior, according to their silicatic composition, as described in the following chapters.

Starting from these materials different mortars have been prepared in order to verify the properties of glass and diss ashes as pozzolanic aggregate and diss fiber as reinforcement.

2.2 Mortars' composition

Marble slurry has been kilned in a muffle furnace at 900°C for 24h, so obtained quicklime was slaked by mixing it with distilled water in a 1:2.5 ratio by weight.

In order to obtain the desired mortars, cullet was grinded with an automatic Resch agate mortar, grinded powder was sieved by means of a 0.125mm sieve.

Diss fibers have been dried to constant weight in an oven at 70°C, afterwards they have been cut by means of a knife mill Retsch SM100 operating at 1500rpm using a mesh of 2 mm.

Diss ashes have been used as obtained after burning.

Tab. 1: Volume ratio of mortars' components

mortar	lime	sand	diss fiber	diss ashes	glass
B	1	3			
V05	1	2.5			0.5
V10	1	2			1
D05	1	1.5	0.5		1
D10	1	1	1		1
D15	1	0.5	1.5		1
D20	1		2		1
C05	1	2		0.5	0.5
C10	1	2		1	

Mortars' have been prepared according to volume ratio presented in table 1. The water to binder ratios of all mortar types have been determined according to standards UNI 1015-2 and UNI 1015-3, by means of workability test described in **3.2**.

2.3 Experimental procedures

Simultaneous thermal analysis (STA) have been performed to characterize materials used in this work. The instrument is a Netsch STA409 Jupiter F1 equipped wth a SiC furnace. The STA have been performed in the range 30-1000°C, heating rate 10°C/min, 20ml/min nitrogen flux and 40ml/min air flux.

Flow table is a Controls 63-L0037-E. According to italian standard UNI EN1015-3 it was used to determine the workability of fresh mortar in order to choose the water to binder ratio that ensure the same behaviour to the different fresh mortars. On fresh and hardened mortars the apparent density has been meausured by filling the sample mould and weighing it.

Thermal conductivity has been determined by means of Thermofluxmeter TA-instruments FOX314, equipped with WinTherm50. The standards ASTM C518 e ISO 8301 has been used as reference.

Three-point bending has been made by means of a Zwick/Roell Z005 universal testing machine, driven by Testxpert II software, according to UNI EN1015-11 standard, span fixed to 100mm, loading rate equal to 0,1mm/min, preload equal to 20N.

Compression tests have been made using a Wance Universal testing machine ETM 501, at a deformation rate equal to 0.5 mm/min.

Water absorption measurement was made according to UNI1015-18.

Measure of apparent density was made by weighing the mould for compression test samples, filling it with the different materials, compacting them by means of flow table and weighing it again.

3 EXPERIMENTAL

3.1 Physical chemical characterization of used materials

As the ratio between binder and aggregates are defined by volume but the simpler way to work is to use weight ratios, for all the raw materials a determination of apparent density was performed. This meausere is particularly important for light materials, such as diss fibers or ashes. Table 2 resumes the apparent density of raw materials used in this work.

Tab.2 Apparent density of raw materials

	Apparent density g/dm^3
Slaked lime putty	1,30
Glass powder	1,30
Sand	1,45
Diss fibers	0,56
Diss ashes	0,08

Slaked lime putty was obtained by kilning the marble slurry at 900°C in a muffle furnace for 24 hours. So obtained quicklime was slaked with distilled water in a 1:2.5 weight ratio. The mixture was carefully stirred in order to promote the completion of the reaction for 10 days before the manufacturing of the mortars.

STA, performed after 10 days, showed that 65.36% of the sample consisted of water; the remaining 34.64% consisted for 30.79% of calcium hydroxide and for 2.61% of calcium carbonate, as shown in figure 1. By expressing the results obtained in reference of the dry product it is more correctly to say that the slaked lime consisted for 88.9% of calcium hydroxide.

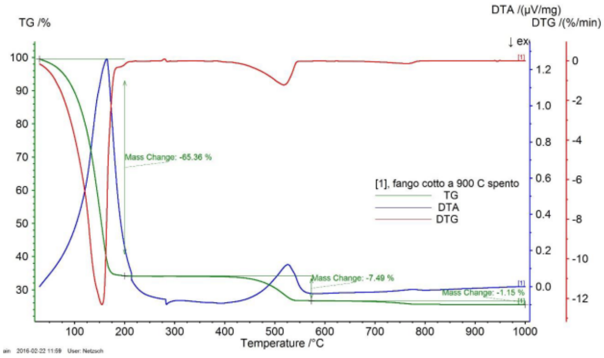

Fig. 1. STA of slaked lime obtained by marble slurry.

According to literature studies [Omran et al., 2006], the glass powder provides a pozzolanic activity as the amorphous silica (SiO_2) can react with lime and forms gels of calcium silicate hydrate (C–S–H). Moreover pozzolanic activity is strongly influenced by glass grainsize [Idir et al., 2012], particularly previous studies [Starinieri et al., 2017, Matos, Sousa Coutinho, 2012] indicate that pozzolanic reactivity is first notable at particle sizes below 300µm, while other authors [Papadakis, Tsimas, 2002] suggest that glass powder with grainsize lower than 100µm may exhibit a pozzolanic reactivity greater than that of fly ashes.
According to these considerations the glass powder used in this work has been ground and sieved with a 125µm sieve in order to ensure a good reactivity.

River sand, consisting mostly of quartz with traces of biotite and feldspars (XRD), was used to prepare the mortars. As aggregate, it does not significantly influence the reaction processes but contributes to the mechanical resistance of the finished product.

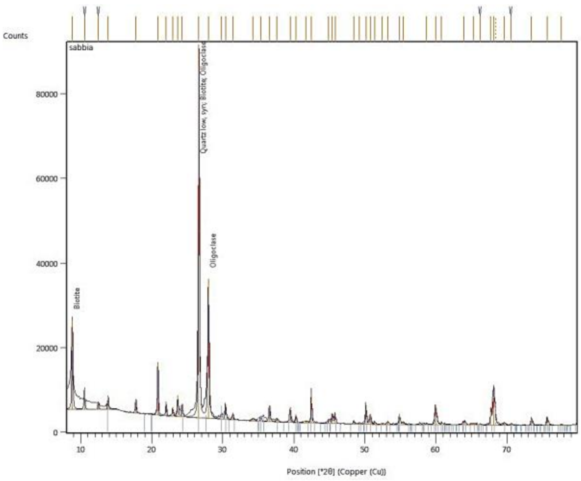

Fig. 2: XRD pattern of river sand.

Diss fibers were analyzed by means of SEM-EDS performed on dry fibers. As shown in figure 3 diss fibers are characterized by the presence of hooks along the axial directions. EDS analysis performed around a single hook revealed that these hooks consists mainly of silica, see figure 4.

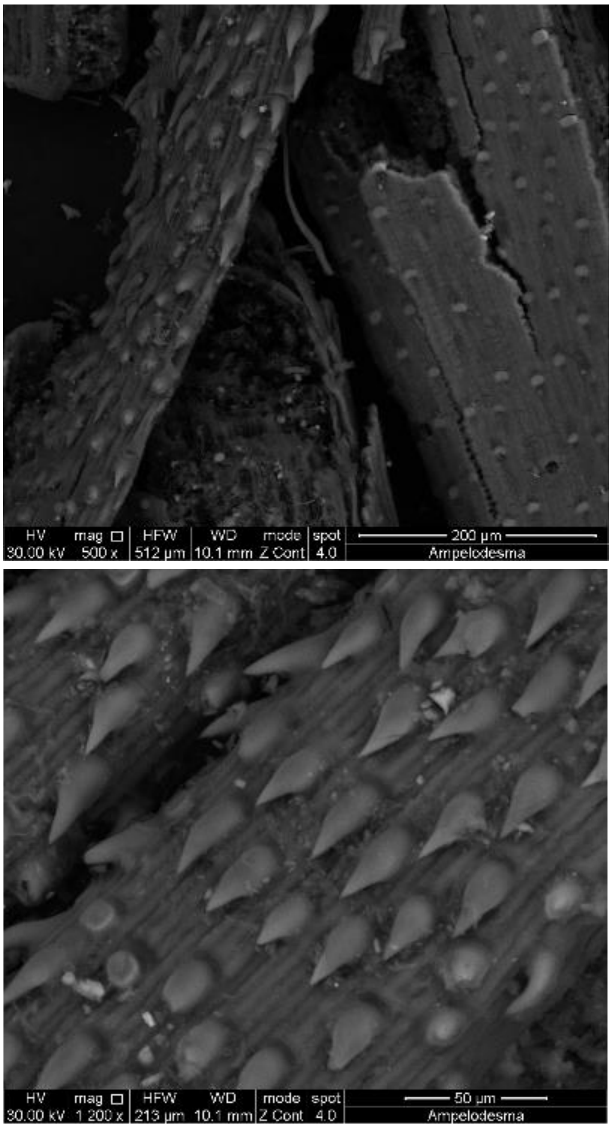

Fig 3 Diss fibers as observed in Secondary electron modes in SEM.

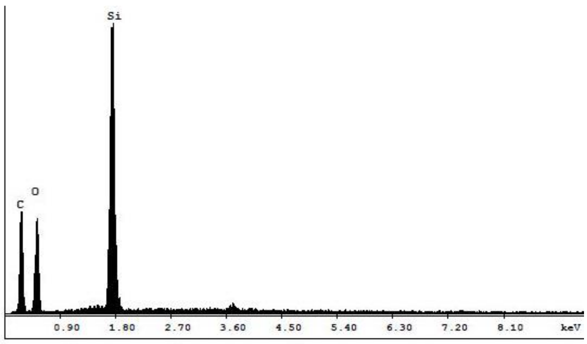

Fig 4 EDS analysis of hookes visible on the diss fibers surface.

The high content of silica in diss fiber raised the idea that diss ashes could be used as admixture for lime. An STA performed on diss fibers showed that around 8% by weight remains as ashes after burning, see figure 5.

Finally, thermal conductivity of compacted diss fibers has been measured. The fibers have been put in a mould, 15x15x4 cm, within a polystyrene panel (30x30x4cm) as shown in figure 6. Thermal conductivity of diss fibers results equal to 0,059 W/mK.

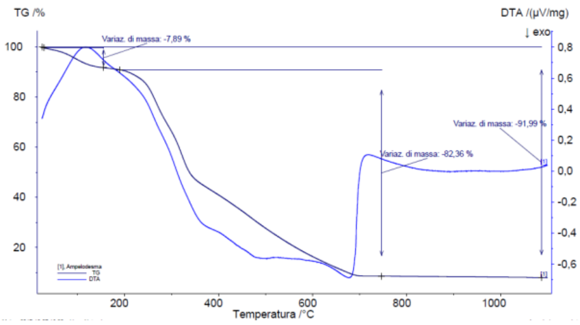

Fig.5: STA on diss fiber, note that total mass loss is equal to 92% including 7.89% of humidity.

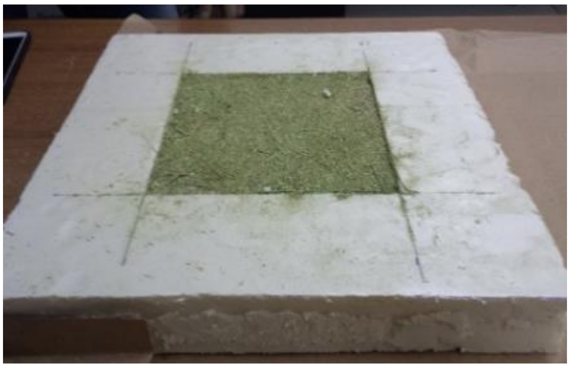

Fig.6: Polystyrene mould filled with diss fiber for thermal conductivity measurementes.

3.2 Mortars' preparation

Mortars have been prepared according to composition illustrated in table 1. Water to binder ratio have been adjusted by means of the following procedures.

Fresh mortars have been prepared on the flow table as shown in fig. 7A, according to procedure described in UNI EN 1015-3 standard, the test has been repeated adding 5% of water by weight until the measured diameter after workability tests, as shown in figure 7B, reaches the value suggested by the aforementioned test. According to this procedure all the mortars had the same workability, regardless of water content.

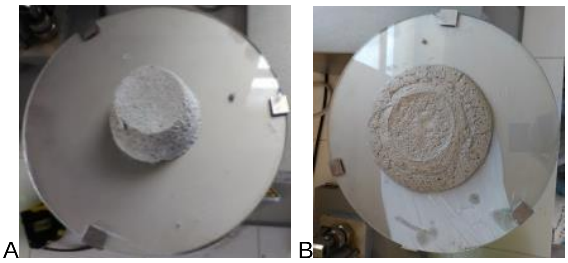

Fig. 7: mortar on flow table before, A, and after, B, workability test.

4 EXPERIMENTAL RESULTS

As described above nine types of mortars have been prepared in order to study the performance of diss fibers and diss ashes as admixtures for lime mortars. In this work the mortars labeled as B, V05 and V10 have been considered as reference with respect to the mortars C05 and C10, in order to verify the pozzolanic behavior of diss ashes. Moreover the mortar V10 has to be considered the reference mortars for D05, D10, D15 and D20 mortars, as it's characterized by the same binder mixed with the same proportion of pozzolanic aggregate.

4.1 Mechanical tests

According to this preliminary consideration results of mechanical characterizations of the mortars are reported in two separated couples of graphics in figures 8 and 9, the first refers to the performance of mortars with diss ashes, the second to the diss fibers' mortars. Particularly figure 8 represent the data relative to mortars without fibers at increasing substitution of river sand with glass, i.e. V05 and V10, or ashes,C05 and C10.

It can be easily noted that the C10 mortars have, more or less, the same properties of B mortars, while the C05 have the same of V05. In both cases the substitution of river sand with diss ashes doesn't produce an increase on mechanical characteristics of the mortars, while glass powder enhanced the behavior of the mortars as clearly highlighted by the results obtained with the V10 mortars.

These results clearly indicate that diss ashes have no significative pozzolanic reactivity, resulting in mortars with the same properties of air hardening ones.

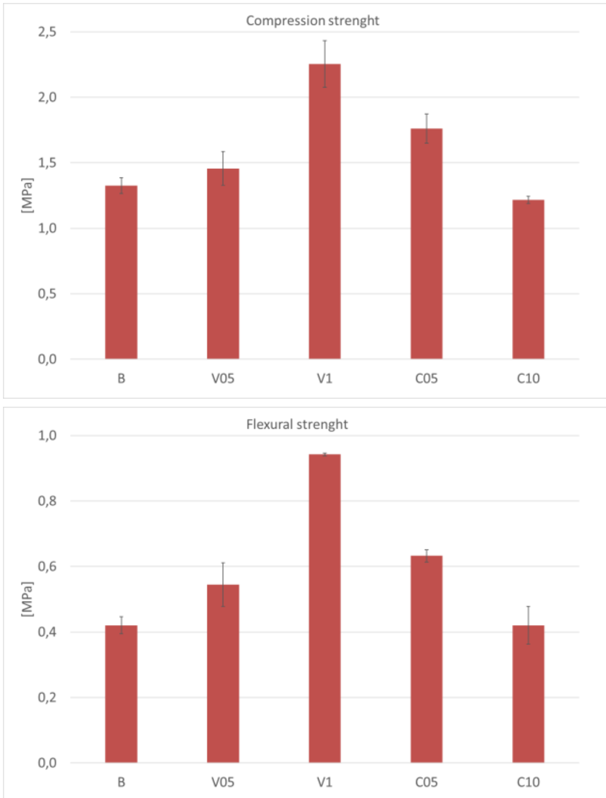

Fig. 8: Compression and flexural strength for mortars prepared with or without diss ashes, after three months of hardening.

On the contrary the use of diss fibers strongly affects the mechanical behavior of proposed mortars as shown in figure 9. Diss fibers have been added to mortars which binder is a mixture of lime putty and glass powder, like the V10 reference, with increasing substitution of river sand with diss fibers from D05 up to D20.

Particularly the compressive strength of the mortars is strongly influenced by the presence of fibers and decreases with increasing fibers amount, while flexural strength shows a slight increase with addiction of fibers with respect to V10 mortar without fibers, but looks like be regardless of fibers amount.

It's interesting noting that D05 mortars have the highest compression resistance, indicating that a low fiber percentage can improve compression resistance even if fibers have lower resistance with respect to river sand. It can be probably due to the hookes that guarantee a high adhesion between binder and fibers.

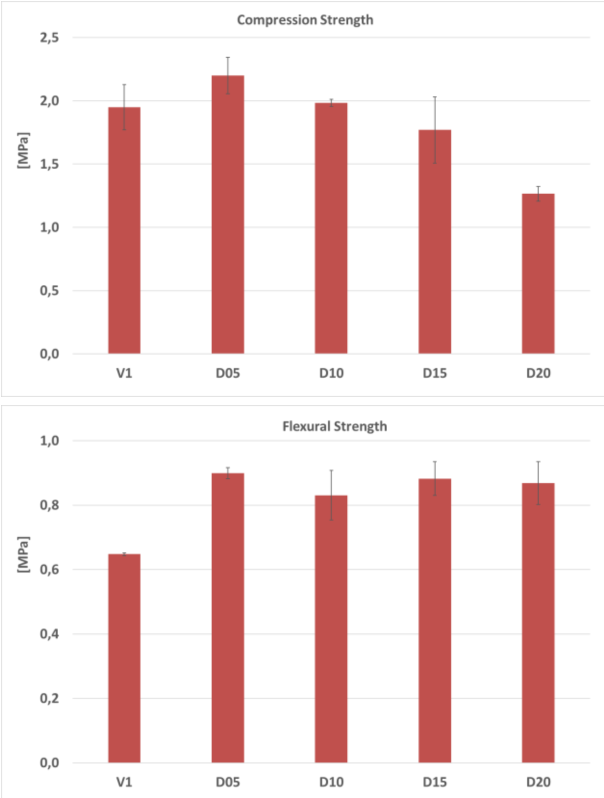

Fig. 9: Compression and flexural strength for mortars prepared with or without diss fibers, after three months of hardening.

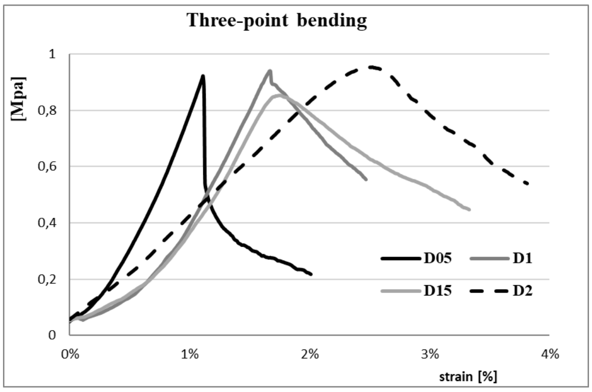

Fig. 10: Three point bending stress strain curves for mortars prepared with or without diss fibers, after three months of hardening.

Finally it's interesting observing the stress strain curve in three point bending of mortars with fibers, figure 10. Although the flexural strength remains constant with increasing fibers percentage the strain at maximum strength increases with fibers' percentage and the post fractural behavior becomes more plastic, with residual strength highlighted up to very high deformation.

4.2 Physical characterization

As the results of mechanical characterization of mortars with diss ashes highlighted that the latter have no pozzolanic behaviour, no further characterizations have been performed on samples C05 and C10.

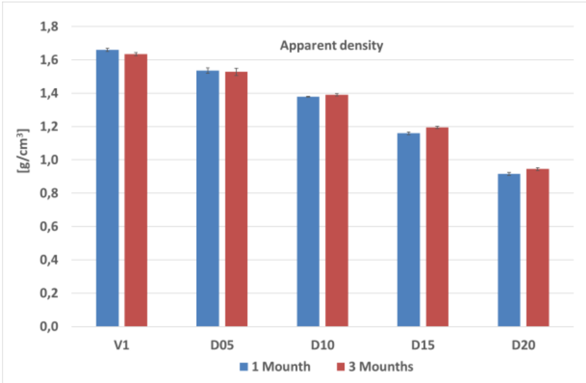

Fig. 10: Apparent density of mortars prepared with or without diss fibers, after one or three months of hardening.

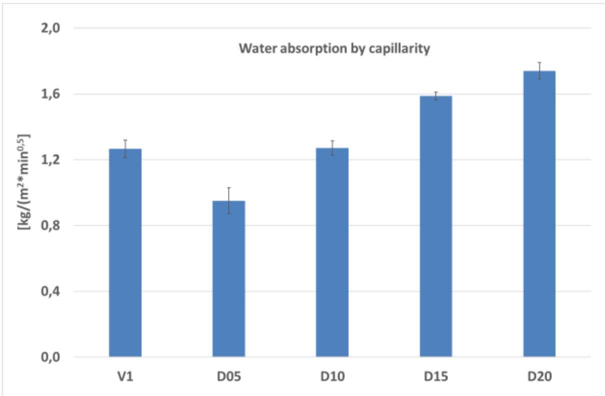

Fig. 11: Water absorption for mortars prepared with or without diss fibers, after three months of hardening.

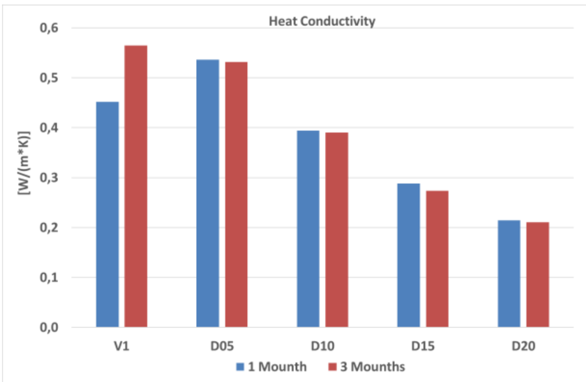

Fig. 12: Heat conductivity for mortars prepared with or without diss fibers, after one and three months of hardening.

Diss fibers based mortars have been characterized with respect to environmental factors. Apparent density of the mortars decreases with increasing fibers' content as expected, but it increases with hardening particularly with higher fibers' content.

At increasing fiber content water absorption increases significantly as Diss is a very hygroscopic material. On the other side thermal conductivity decreases quite rapidly with increasing fiber content. It’s worth noting that thermal conductivity increases with hardening in mortars without fibers, as hardening leads to a more compact structure. On the contrary hardening produces no effect on thermal conductivity of fiber rich mortars as in this case this property depends more on insulating capability of the fiber than on binder’s characteristics.

5 CONCLUSIONI

In this study the opportunities offered by Diss ashes and fibers have been investigated for their use as possible pozzolanic admixture and reinforcement for lime mortars respectively.

Diss ashes showed a neglibile pozzolanic behaviour highlighted by mechanical properties of mortars obtained with this admixtures similar to air hardening ones.

Diss fibers offered interesting properties increasing toughness of mortars and their insulating properties.

Particulalry a low fiber content increases both compressive resistance and flexural toughness, decreasing slightly mortar density and thermal conductivity.

On the contrary higher fibers content leads to lower compression resistance while flexural strength seems to be not affected by fiber content. These results can be explained considering that Diss fibers has siliceous hooks along the surface that can increase adhesion between binder and fibers resulting in a high flexural resistance even at high fiber content coupled with an increased toughness as shown by post fracture behaviour of the mortars.

Finally at high fibers content, particularly D20 mortar, thermal conductivity reach the value 0.2W/mK. This result allows to classify the mortar as an insulating plaster according to Italian standard UNI EN998-1.

ACKNOWLEDGMENTS

Sarco s.r.l. for glass supply.

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