Mechanical-physical experimental tests on lime mortars and bricks reinforced with hemp

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Abstract. Hemp is an agricultural product used for various applications. In the Civil Engineering field, only a limited use of this natural material, called the "green pig" since exploitation of all its constituent parts is allowed, has been done. For this reason, in the paper an experimental activity on lime mortars and bricks reinforced with hemp components has been performed. Compression and bending tests have been carried out on specimens manufactured with hemp shives and fibres, respectively. The achieved results have shown that hemp products change the failure modes from brittle to ductile, leaving basically unaltered the strength capacity of reinforced specimens with respect to unreinforced ones.

INITIAL REMARKS

In recent years there has been a renewed sensitivity to technical aspects related to the durability of interventions and the use of low environmental impact systems, shifting the interests of both research and building market towards sustainable solutions both for new [1, 2, 3] and existing [4, 5, 6] constructions. Since the Italian territory still suffers due to the age of its housing stock, the recent events have given new and important research incentives which, because of changed standard codes, is beginning to use hemp as a cutting-edge material in constructions.

Hemp is well suited to several uses in the building industry due to its physical properties, such as a low specific weight, a high insulating power, which derives from the presence of silicon atoms "trapped" in the cellulose matrix and in the lignin, and a good hygroscopic behaviour, which makes hemp fibers as natural environmental humidity regulators. These properties are of particular importance in the so-called "light" building field, consisting of mats and panels with high thermal and acoustic insulation for claddings, light blocks for partitions and lightened screeds for laying of floorings. If these properties are widely used for non-structural components, the hemp mechanical characteristics, such as the high tensile strength, compared to other natural fibres, and the high mechanical wear resistance, make this material ideal for the "heavy" building field, which both bearing masonry blocks and fibre-reinforced mortars for masonry and plaster belong to. In this framework the current research activity founded on an eco-sustainable approach is shifting.

From the hemp stem it is possible to extract shives and fibres (Figure 1), the latter representing the covering cortical layer used, thanks to versatility and recyclability characteristics, in the textile and paper industries. The shives are constituted by the inner part of the stem where, during the growth of the plant, the cellulose is transformed into lignin, trapping within the matrix different substances and, thus, making it less valuable and desirable. However, thanks to the substances present in the cellulose and lignin matrix, shives acquire all the different physical and mechanical properties that distinguish them.

The proposed research activity follow two different projects: the first on the use of hemp fibres to manufacture fibre-reinforced lime mortars for plaster and masonry walls, whereas the second is based on shives for the production of load-bearing masonry bricks. In the following sections the results of an experimental campaign framed within the above topics are illustrated and the benefits deriving from the use of hemp components are clearly highlighted.

(a) (b)

FIGURE 1. Fibres (a) and shives (b) as hemp components used in the Civil Engineering field

EXPERIMENTAL TESTS ON MORTARS

Regarding the experimentation on lime mortars reinforced with hemp fibres, different targeted campaigns have been firstly conducted to identify the effect of disparate percentage of fibres, assessed in terms of weight, on the mixture workability. In fact, being a very hygroscopic material, the natural fibres are involved in the packaging process of the mortar, altering its workability and resistance.

This is because in a first phase, corresponding to the mixing of components, fibres tend to absorb the water used for manufacturing, reducing the mortar fluidity and, therefore, the ease of realization, forcing the operator to add additional quantities of water. Subsequently to the mortar setting and hardening, fibres tend to gradually release the imbibition water, also as a function of the ambient moisture content, thereby increasing the dough porosity and reducing the mechanical strength.

From workability tests (Figure 2), it appears that the best mixtures have a water / binder ratio in terms of weight equal to 21.5%, it being equal to the water maximum value that can be used for the M5-M15 hydrated lime mixture.

Bending tests have been performed on three original (unreinforced) specimens and on other twelve specimens, the latter being divided into four groups, each one composed of three samples, representative of the four different percentages of fibres (0.5, 1, 1.5 and 2%) considered. Some of the prepared specimens are shown in Figure 3a. From these experimental tests it is observed that the presence of fibres changes from brittle to ductile the failure modes of mortars, increasing the ultimate displacement. This result is obtained thank to the stitching effect given by fibres (Figure 3b). For the sake of example, in Figure 4 the comparison between the unreinforced specimen and that reinforced with 0.5% of fibres is shown. The presence of fibres gives rise to a slight reduction of stress, which is averagely equal to 1.56 MPa instead of 1.65 MPa for the unreinforced specimen. Therefore, a stress reduction of about 5% is achieved, but the strength class of the reinforced mortar is not changed in comparison to the initial one. On the other hand, the ultimate displacement is 0.63 mm instead of 0.49 mm for the unreinforced specimen, thus leading to a performance increase of about 29%.

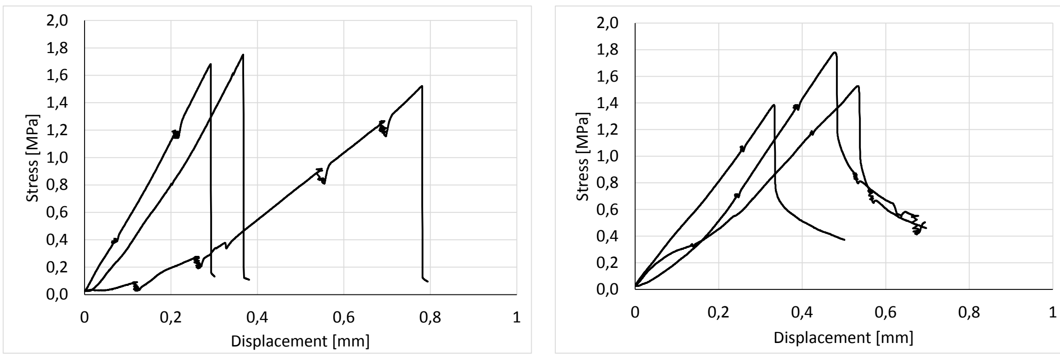
Other experiments have determined the influence of the fibre length on the compression strength, in order to assess the internal confinement effect deriving from their presence as diffused reinforcement of the mixture. Moreover, the influence of fibres, having an important effect on the crack stitching due to the cement matrix brittle nature, on the bending moment resistance has been evaluated.

(a) (b) (c)

FIGURE 2. Mixing initial phase (a) and shaking table test (b, c) on fibre-reinforced mortar

(b) (b)

FIGURE 3. Preparation of specimens (a) and sewing effect of fibres at the bending test end (b)



(a) (b)

FIGURE 4. Bending tests on unreinforced (a) and fibre-reinforced (0.5%) (b) mortars

After the tests, by analyzing the breaking surfaces of specimens, the presence of intact fibers, often forcibly extracted from the cement matrix due to both an adequate anchoring but an insufficient length, is denoted. In particular, it has been observed that fibre lengths less than 5.0mm are ineffective, while lengths in the range [5.0 ÷ 15.0] mm are properly anchored, showing an effective stitching effect.

EXPERIMENTAL TESTS ON BRICKS

With reference to the use of hemp shives for packaging of load-bearing masonry blocks, in the mixture the following proportions and percentages in terms of weight have been used: 1 : 1 of silica sand and volcanic sand, 12.5% of hydrated lime (type M5), calculated on the total weight of the aggregates, and water / lime ratio of 20.0%.

Shives having lengths of 6 mm and 15 mm have been used as brick basic components. The shive percentage has been changed up to 2.0% in terms of weight, which corresponds to a volume occupied of about 35-40%. For these specimens it has been observed a significant density reduction in comparison to that of unreinforced bricks. In Figure 5 some specimens after the maturing phase are shown.

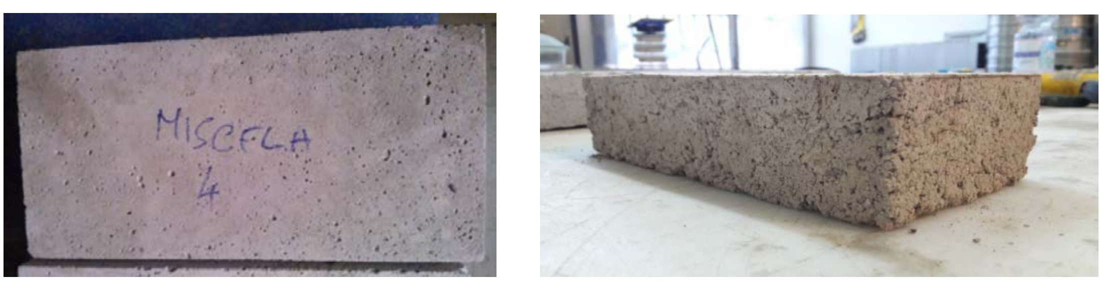


FIGURE 5. Brick specimens used for compression tests

Experimental compression tests on 5.5x12x25cm specimens with maturing of 28 days have been carried out. In Figure 6 results of these tests are shown in terms of failure compression stress. From the diagram it is noticed that, if reference is made to the average trend line of experimental results, the achieved stress values are intermediate between those of poroton (load-bearing masonry type) and those related to gasbeton (non-structural light blocks).

Therefore, even if the resistance of investigated bricks can be considered as satisfactory, further experimental campaigns by using also gravel in the mixture should be performed in order to improve the compression stress, so leading towards bricks to be used as load-bearing masonry components.

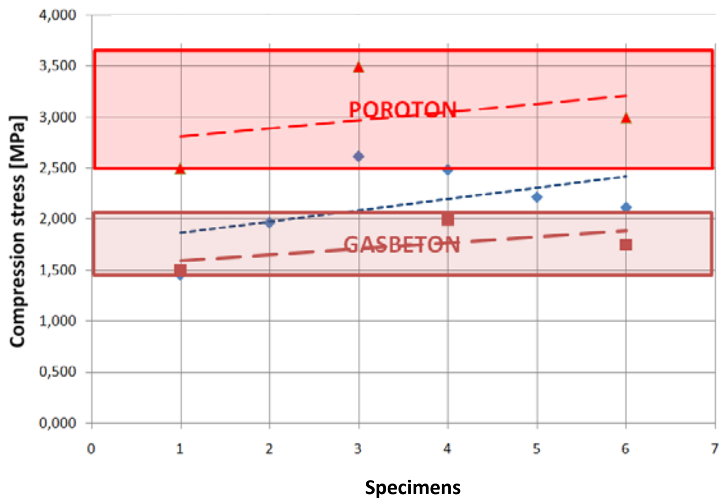


FIGURE 6. Compression test results on bricks reinforced with hemp shives

CONCLUSIONS

In the paper the physical and mechanical behaviour of mortars and bricks reinforced with hemp fibres and shives, respectively, has been shown on the basis of an experimental tests campaign.

Bending moment tests performed on fibre-reinforce mortars have highlighted that hemp fibres allow to increase the ultimate displacement of specimens up to an average value of about 29%, by changing also their failure mode from brittle to ductile thanks to the stitching effect of cracks provided by fibres.

Compression tests on bricks reinforced with shives, characterized by low density, give rise to satisfactory values of the ultimate stress, which nevertheless appear to be averagely 30% lower than those of poroton blocks used for load-bearing masonry walls. Therefore, as further development of the study, additional experimental tests should be performed on specimens manufactured also with gravels in order to improve the failure compression stresses.

REFERENCES

1. F. Clementi, S. Lenci and T. Sadowski, Fracture characteristics of unfired earth, International Journal of Fracture 149, 193-198 (2008).
2. S. Lenci, Q. Piattoni, F. Clementi and T. Sadowski, An experimental study on damage evolution of unfired dry earth under compression, International Journal of Fracture **172** (2), 193-200 (2011).
3. S. Lenci, F. Clementi and T. Sadowski, Experimental determination of the fracture properties of unfired dry earth, Engineering Fracture Mechanics **87**, 62-72 (2012).
4. B. Faggiano, A. Marzo, A. Formisano and F.M. Mazzolani, Innovative steel connections for the retrofit of timber floors in ancient buildings: A numerical investigation. Computers and Structures **87** (1-2), 1-13 (2009).
5. A. Formisano and F.M. Mazzolani, On the selection by MCDM methods of the optimal system for seismic retrofitting and vertical addition of existing buildings, Computers and Structures **159**, 1-13 (2015).
6. G. Terracciano, G. Di Lorenzo, A. Formisano and R. Landolfo, Cold-formed thin-walled steel structures as vertical addition and energetic retrofitting systems of existing masonry buildings, European Journal of Environmental and Civil Engineering **19** (7), 850-866 (2015).