

ICBBM 2021



Proceedings of the 4th International Conference on Bio-based Building Materials

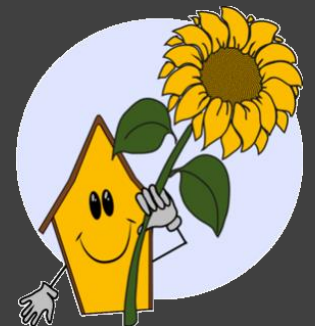
16-18 June 2021, Barcelona, Spain

Editors :

Sofiane Amziane & Mohammed Sonebi

Associate Editor :

Jonathan Page



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SHEEP WOOL AS FIBER-REINFORCEMENT OF GYPSUM COMPOSITES

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Abstract

Depending on the intended use, some cement-based construction materials, such as paste, mortar and concrete, need to be fibre reinforced. In these materials, fibres play the same mechanical role as ossein, the elastic collagen fibres in animal bones that guarantees the resistance to fracture. Although commonly used fibres are made of various materials, such as steel, glass, polymers etc., animal and plant fibres can also be used in building materials. Among them, wool of sheep, a waste material in several countries, can effectively reinforce pastes, mortars and concretes. In addition to the research already performed in the field of cement-based composites, the use of sheep wool as reinforcement of gypsum-based composite is experimentally investigated herein for the first time. As a result, sheep wool reinforcement provides high fracture toughness, due to an excellent adhesion, and could be a valid alternative to the current industrial fibres in reinforced gypsum manufactures.

Keywords:

Sheep wool fibres, Gypsum-based composite, Mechanical properties, Microstructure

1 INTRODUCTION

In the construction sector, industrial fibres made with glass, basalt, polymer (polypropylene, polyester or PVA) or steel, play a fundamental role in improving the behaviour of brittle matrix composites. Under tensile loads, a fibre-reinforcement can increase fracture toughness and the resistance to crack propagation. The tensile strength of brittle composites improves as well, especially when a large volume of fibres is added to the matrix (Józwiak-Niedźwiedzka and Fantilli 2020).

Apart from the common man-made fibres, the interest in organic fibres has recently increased. As animal and vegetal fibres are eco-friendly materials, annually renewable, and totally recyclable, they meet the requirements of green building rating systems and, therefore, they are frequently used as construction materials (Józwiak-Niedźwiedzka and Fantilli 2020).

Wool, despite its importance as a textile fiber has little value in Europe. It was found that only 8% of Swedish wool is used for textile production, with over 75% of wool produced ending up as a waste product. This is due to the current restrictions on the use of agricultural by-products, classifying wool as a waste product with no economic incentives to valorize the wool beyond disposal (Martin and Herlaar 2021).

Some researchers showed that the addition of sheep wool fibres, as well as hemp fibres, treated or not with the atmospheric plasma, can improve the mechanical performances of cementitious mortar (Fantilli et al. 2017, Štirmer et al. 2014). Nevertheless, the practical application of these cement-based composites must be supported by studies concerning the chemical degradation of bio fibres in alkaline environment (Fantilli and Józwiak-Niedźwiedzka 2020). Alternatively, animal and vegetal fibres can be used to reinforce brittle matrix containing other binders, such as gypsum, which is widely applied as construction material. Gypsum-based composites are used to finish surfaces of new and renovated walls, and ceilings as well. Partition elements made with gypsum-based plaster act as an acoustic and fire barrier. In addition, gypsum is lighter than cement-based composite, and retains its physical and chemical properties so that it can be recycled endlessly.

Although in many cases gypsum elements do not have structural functions, an increment of toughness is desirable. In such circumstances, brittleness may be appreciably reduced by combining gypsum with natural fibres (Iucolano et al. 2015), instead of polymeric (Zhu et al. 2018, Mukhametrakhimov et al. 2019) and glass (Wu 2004) fibres. These bio fibres, like hemp, can be used to reinforce a cost-effective and more environmentally friendly gypsum plaster (Iucolano et al. 2018, Iucolano et al. 2019).

As sheep wool, which is a waste material, provides the same performances of hemp in fibre-reinforced cement-based mortars (Fantilli et al. 2017), the goal of this work is to analyse the feasibility of reinforcing gypsum composites using wool as a valid alternative to vegetable and other industrial fibres.

2 EXPERIMENTAL ANALYSIS

As shown in Table 1, Series A is only composed by plain gypsum paste, with a water-binder ratio $w/b = 0.47$. Wool fibres are added to the Series B in the amount of 12 grams (about 1% in volume), whereas the w/b of the gypsum paste increases ($w/b = 0.49$), because of the water absorption of the fibres.

Tab. 1: Composition of the gypsum-based composites.

Series	Wool fibres (g)	Gypsum (g)	Water (g)	Type of curing
A	0	990	465	75 days in normal condition ($20 \pm 1^\circ\text{C}$, $50 \pm 5\% \text{RH}$)
B	12	990	510	

The amount of the components reported in Table 1 are sufficient to cast three prisms ($40 \times 40 \times 160 \text{ mm}^3$) with each series. All the prisms have been cured in normal laboratory conditions ($20 \pm 1^\circ\text{C}$ with $50 \pm 5\% \text{RH}$) and, after 75 days, the specimens have been tested in bending and compressions.

According to EN 196-1 (2016), the flexural strength can be measured by means of the three-point bending test shown in Fig.1a. The same testing machine, but with a different apparatus, is also used to determine the compressive strength (see Fig.1b).

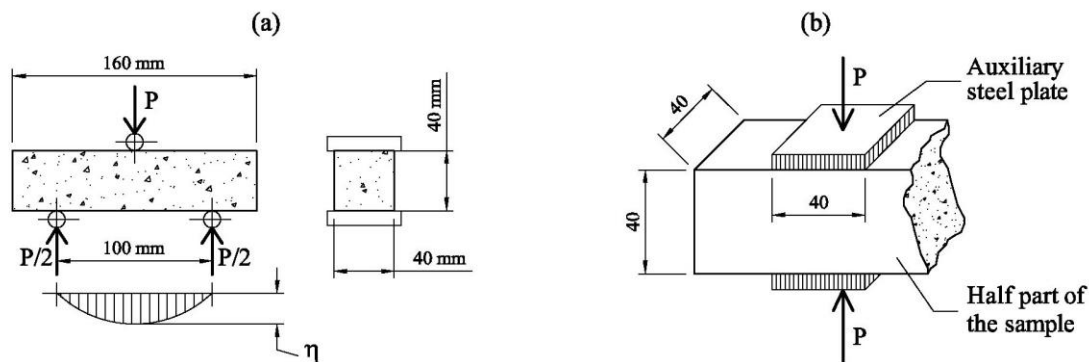


Fig. 1: (a) Three point bending test and (b) compression test on gypsum composites.

The microstructure of constituent materials as well as paste has been investigated using JEOL JSM-6460 LV high vacuum scanning electron microscope. The paste microstructure was analysed on the fresh split surface of the gypsum-based composites to avoid any influence of carbonation.

3 TEST RESULTS AND DISCUSSION

Fig.2a shows the typical deflection – load curve, η - P , measured during the flexural tests. The ascending branch of this curve finishes at the maximum load P_{\max} , in correspondence of which the flexural strength of the gypsum-based composite, σ_{flex} , can be computed.

The descending branch of the η - P curve defines the toughness of the gypsum-based composites. In accordance with the tests already performed on wool-reinforced cementitious mortars (Fantilli et al. 2017), the flexural toughness can be defined by means of the inelastic displacement, $x = \eta - \eta_p$, vs. non-dimensional load, $y = P/P_{\max}$, as reported in Fig.2b. The area A_F delimited by the curve x - y (Fig.2b), up to $x = 2 \text{ mm}$, is herein used to quantify the flexural toughness.

The main flexural properties of the gypsum composites (i.e., P_{\max} , η_p , and A_F) are collected in Table 2. In the last column of this Table, the values of the maximum compressive load, P_c , are also reported.

Tab. 2: The main properties measured in the mechanical tests

Series	Specimen	η_p (mm)	P_{\max} (N)	A_F (mm)	P_c (N)
A	A1	1.30	2459	0.004	21488
	A2	1.26	2346	0.005	23284
	A3	1.31	2185	0.004	22150
B	B1	0.99	1983	1.094	18727
	B2	1.15	1610	1.109	11460
	B3	1.30	2036	0.875	16770

To compare the performances of all the gypsum-based composites investigated herein, the average values of σ_{flex} and σ_c are reported in the histograms of Fig.3a and Fig.3b, respectively.

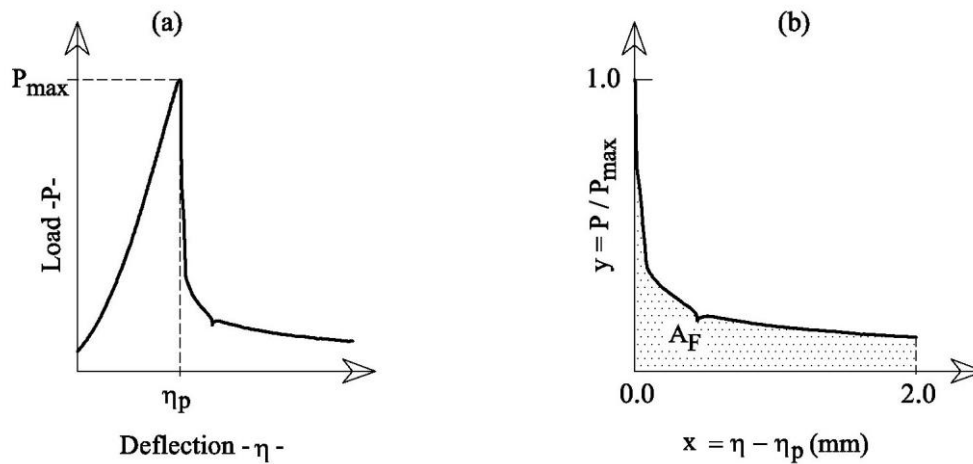


Fig. 2: The results of the flexural tests: (a) deflection-load and (b) post-peak curve.

In wool fibre-reinforced gypsum (Series B), compressive and flexural strength are 20% lower than those of plain gypsum (Series A). This is due to both the higher water/binder ratio and, according to literature data (Zhu et al. 2018), to the large content of fibre (i.e., 1% in volume). Vice-versa, the average flexural toughness, which indicates the capability of the composite to maintain residual stresses on the crack surfaces, is practically zero in absence of fibres. This is evident in Fig.3c, where the average values of A_F are compared in the two series.

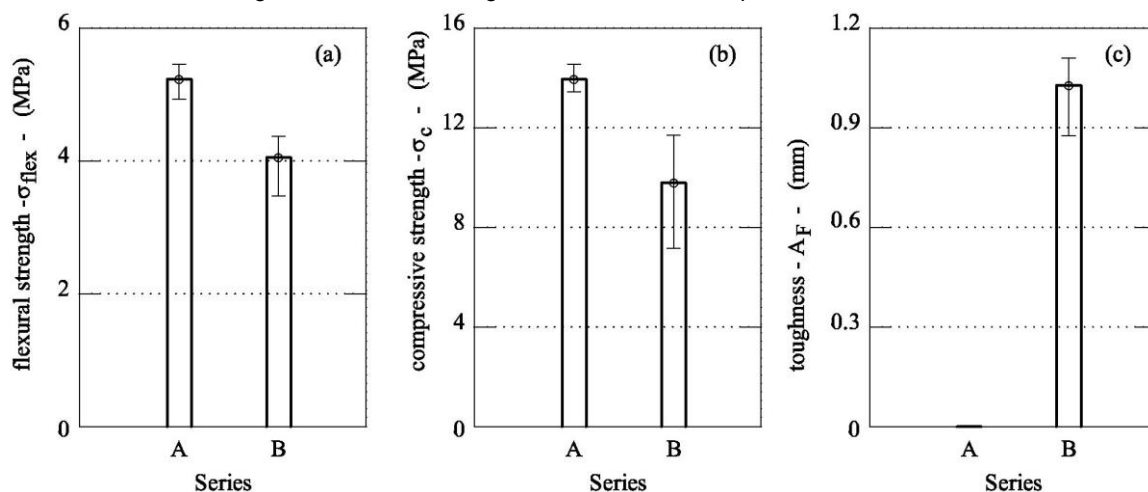


Fig. 3: Average values of (a) flexural strength, (b) compressive strength, and (c) flexural toughness in the three series of gypsum-based composites

These results are consistent with those obtained by reinforcing gypsum composites with industrial fibres. Zhu et al. (2018) reinforced gypsum paste ($w/b = 0.6$) with 1.2% in volume of polypropylene fibres having a diameter of $10 \mu m$ and a length of 6 mm. This gypsum composite showed a flexural strength of 4.84 MPa (similar to the flexural strength of Series B) and a toughness in bending $A_F = 0.64$ mm which is only 60% of that obtained by using wool fibres. Thus, wool fibres can bridge the cracks better than polypropylene fibres and is a valid substitute of the current manufactured fibres used to reinforce gypsum.

At the same time, the morphological analysis of the fresh split surface of the gypsum-based composites confirmed very good adhesion between sheep wool fibres and the gypsum matrix (Fig. 4). In SEM microphotograph, sheep wool fibre (Fig. 4b) are completely covered with gypsum crystals when it is used as reinforcement. The presence of crystals is evident in the fibres that have been pulled out of the gypsum matrix (Fig.4b).

4 CONCLUSIONS

Based on the research carried out on gypsum composites, plain and reinforced with sheep wool fibres, the following conclusions can be drawn:

- Mechanical tests reveal the influence of the water/binder ratio on the strength of gypsum composites, whereas the fracture toughness depends on the fibre content.
- The fracture toughness of the wool-reinforced gypsum is remarkably larger than that measured on propylene-reinforced composites and may result from the excellent adhesion of the wool to the gypsum matrix.

Further studies will be devoted to comparing the performances of wool-reinforced gypsum with those of hemp-reinforced gypsum.

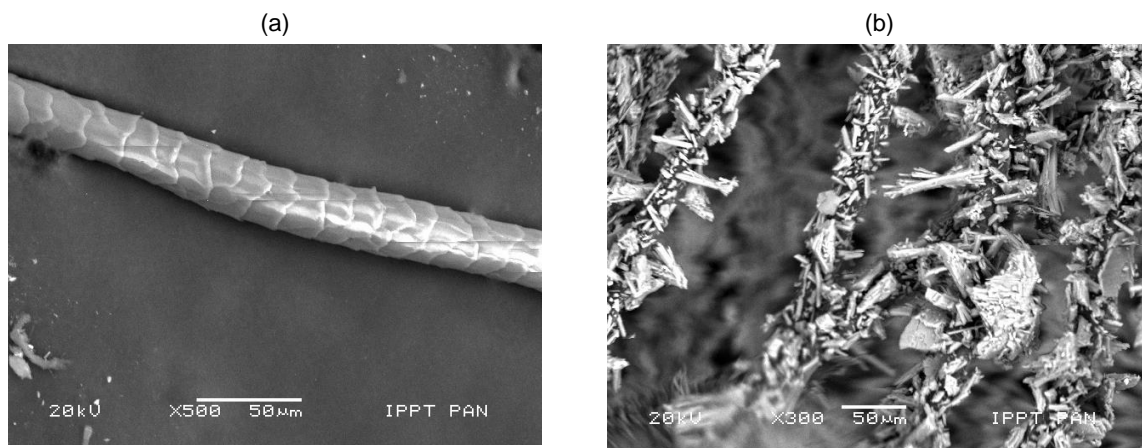


Fig. 4: SEM microphotograph of a: (a) singular sheep wool as constituent material, (b) single sheep wool fibres in analysed paste.

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