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SHEEP WOOL – A NATURAL MATERIAL USED IN CIVIL ENGINEERING

BY

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Abstract. In recent years, became increasingly common the use of natural fibers in the civil engineering sector, as a part of energy-efficient and sustainable trends. In Romania, the breeding of sheep represents a traditional activity. Anually, important quantities of resulted wool are treated as wastes, being burned or buried. Several researches demonstrated good properties of sheep wool fibres which recommend them in insulation purposes or in reinforced composited obtaining.

The purpose of this paper is to highlight the possibilities of sheep wool usage as a building material. This paper is important because, at present, the knowledge and the application of sheep wool fibers in this sector are relatively limited and treated with some doubts.

Keywords: insulation; composites; eco-friendly; building, properties.

1. Introduction

Worldwide, the cement production is related to important gas emissions (for example, CO_2, SO_2) which increase the global warming potential. An appropriate effect is generated by the process of buildings' heating during the

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cold season. In this context, the reduction of energy consumption during the building materials manufacture or to the process of domestic heating, became a great challenge of our century (Şerbănoiu *et al.*, 2014a, b).

Sustainability and energy efficiency of buildings are current issues, mainly because this sector is responsible for 40% of CO_2 emissions and energy consumption (Korjenic *et al.*, 2015). Therefore, more sustainable contructions which comply with the comfort standards and take into account gas emissions decreasing and local building materials with ecological properties are required nowadays (Dikmen & Ozkan, 2016; Şerbănoiu & Timu, 2016; Zach *et al*., 2012).

The use of natural materials in building industry is supposed to reduce the production costs and to contribute to significant improvements of environment quality. The aim of this paper is to highlight the possibility of sheep wool usage in buildings engineering, as a part of the most complex concept of eco-friendly materials and green concrete production.

2. Sheep Wool as a Natural Fibre with Properties Suitable for Civil Engineering

Natural fibres present an increasing interest for applications in civil engineering, as in many other sectors such as military, industrial, space craft, and biomedical. The first researches on natural fibres were conducted on their usage in non-structural parts due to their low resistance and moist degradation. Nowadays, besides thermo-acoustical applications, natural fibres are increasingly used as reinforcement for different kinds of composites in building industry, being an alternative to synthetic materials due to their easy availability, renewability, low costs, light weight, high specific strength and stiffness (Saxena *et al*., 2011).

The main categories of natural fibres used in composite development are plant, animal, and asbestos fibres. Plant fibres are predominant in such of purpose usage due to their higher renewability, recyclability, and availability (Saxena *et al*., 2011).

In the last decade, sheep wool was reported as a natural material used in civil engineering, for thermal and acoustic insulations (façade and roof insulations) (Štirmer *et al.*, 2014), or in composites with different matrices (polymeric, earthern or cementitious) (Grădinaru *et al.*, 2016; Bucişcanu, 2014; Štirmer *et al.*, 2014; Zagarella *et al*., 2014; Aymerich *et al*., 2012; Galán-Marín *et al*., 2012; Galán-Marín *et al*., 2010).

In European Union, there are about 90 million sheep which produces 270,000 tons of wool (Štirmer *et al*., 2014). Unfortunatelly, during the last decades, large amounts of wool were treated as wastes and burnt or landfilled (Bucişcanu, 2014).

As a building material, wool is recommended by its main properties:

a) wool is a natural fibre with mechanical resistance, but also to bacteria and at burning;

b) wool fibres are good absorbers of noise;

c) wool manipulation do not put in any danger the health of workers;

d) wool is a renewable material and eco-friendly.

3. Sheep Wool as Thermal and Acoustic Insulator

In the last years, "green materials" became very important for acoustical applications. A wide variety of natural fibres represent candidates for such purposes, such as kenaf, hemp, coconut, mineralized wood, flax, sisal, cork.

Sheep wool shows good acoustical performances, being adequate as sound absorber in acoustic rooms, as noise barrier or as vibration insulator (Korjenic *et al.*, 2015). Sheep wool panels have an absorption coefficient of about 0.84 at 2,000 Hz, slightly lower than rock wool, polyester or kenaf fibres, but higher than glass wool, polystyrene, mineralized wood fibres, cellulose or rubber grains. It has also a very low index of impact noise reduction under concrete slab (ΔLw = 18 dB), almost equal with cork, but much smaller than glass wool or expanded polystyrene (31, 30 dB respectively), even than wood wool (21 dB), cellulose (22 dB) or coco fibres (23 dB) (Asdrubali, 2007).

Sheep wool is considered a material which cannot be processed in products with densities higher than 100 kg/m^3 because of the fibres' resilience, and due to the larger diameter of its fibres than commonly used man-made mineral fibres (fibreglass or rock wool). Sheep wool can improve by up to 6 dB the transmission loss on plasterboard walls, or can be used as vibration insulator and cavity absorber, providing improvements of up to 10 dB (Ballagh, 1996).

Wool fibres are resistant at burning. They burn slowly with a slight sputtering when flame is present (Zach *et al.*, 2012; Saxena *et al.*, 2011). Comparative to polystyrene, the most common material used nowadays in thermal insulation of buildings which is characterized by a very high flammability with toxic fumes producing (Zach *et al.*, 2012), sheep wool has the advantage that it is a self-extinguish material.

As a thermal insulator material, the sheep wool is characterized by a comparable thermal conductivity to glass wool and polystyrene foam (0.037 W/mk, 0.032,...,0.04 W/mk, and 0.033,...,0.035 W/mK, respectively). On the other hand, its embodied energy is much smaller compared to those two previous mentioned materials (0.4 Gj/m^3, 0.83 Gj/m^3, and 3.03 Gj/m^3, respectively) (Bucişcanu, 2014).

Wool fibers are more hygroscopic than any other fibres. They are able to take up moisture in vapour form. As a result, wool can easily absorb up to 20%,...,35% of its weight in moisture without feeling damp or clammy (Korjenic *et al*., 2015; Bucişcanu, 2014; Galán-Marín *et al*., 2012, Saxena *et al*., 2011). As a result of moisture content increasing, the thermal conductivity coefficient does not change significantly. Another advantage of its high ability to absorb moisture is the prevention of condensation, regulation of humidity and creation of a pleasant indoor atmosphere (Zach *et al*., 2012). Water absorption capacity of sheep wool is significantly higher compared to glass wool (0.2%) or polystyrene foam (0.03,...,0.1%) (Bucişcanu, 2014). Even if it accumulates moisture on the insulation cold side, this is in smaller quantity than in the case of mineral wool. The global warming and acidification potential are with 95% smaller than in the case of mineral wool (Volfa *et al*., 2015).

4. Clay-Based Composites with Sheep Wool Fibres as Reinforcement

Wool fibre mainly contains a protein called *keratin*. Its resistance and insolubility are given by disulfide bridges performed in its structure by cysteine (a sulphur-rich amino acid). Keratin does not dissolve in cold or hot water and does not breakdown into soluble substances (Štirmer *et al*., 2014; Bucişcanu, 2014). In the same time, wool is characterized by an excellent elongation and elastic recovery (Saxena *et al*., 2011).

As a material for reinforced composites, sheep wool may be used *per se* or after some chemical treatments in order to improve its adherence at the polymeric matrix. Composites obtained from geo polymeric matrix (inorganic alumina silicate materials with good mechanical properties and thermal stability) and 5% Wt sheep wool fibres (previously degreased with solvents and alkali to improve the interaction with the matrix) presented a homogeneous fibre distribution and an increasing of flexural strength and failure/fracture characteristics by 40% (Bucişcanu, 2014).

Because natural protein fibres did not have much resistance to the alkalis action, researches were conducted rather toward the clay-based composites than cementitious composites.

Galán-Marin *et al*. (2010) studied the feasability of sheep wool fibres with a soil matrix, developing a soil composite stabilized with alginate and reinforced with unprocessed sheep wool fibres in small amount (0.25%,...,0.5%). Alginate was used as binder instead of cement, being a natural and non-toxic polymer extracted from seaweed. The role of wool fibres was to prevent the visible shrinkage cracks resulted as a consequence of natural drying process. After testing, the authors concluded that the specimens made only of soil failed quickly and without warning. The addition of wool fibers helped the samples to do not complete dezintegrate after the final failure, and increased with 37% the strength to compression. Wool and alginate additions increase the flexural strength with 30%, and doubled the specimen performances to compression. The wool/soil ratio concluded to be optimum for a high strength soil composite obtaining was only 0.25%.

In case of soil composites, there were reported tensile shrinkage cracks due to the rapid and non-uniform drying. Their occuring may be prevented by fibres reinforcement, the role of fibres reinforcement being to bond the soil particles. Aymerich *et al*. (2012) studied the flexural strength on the earthern specimens made of different percentages (2% and 3%) and lengths (2 and 3 cm) of sheep wool fibres, and reported that the sheep wool fibres increased the residual strength, the ductility and the energy absorbtion of the material after the first cracking. The length of fibres is directly proportional with the post-fracture response at the large deflection of the material. In case of macrocracks, fibres have a very good performance as strengthening mechanisms, like frictional fibre pull-out and bridging.

Galán-Marin *et al*. (2012) studied the influence of water absorbtion of wool fibres in three different mixtures, each one included a different type of soil. During the manufacture process of the soil-wool-alginate composites, fibres expanded due to water absorbtion. Microscopically, they were observed to push away the soil and, after drying, they shrank back, resulting very fine voids around themselves. These voids conducted to a higher material porosity and to a smaller degree of friction among fibres and soil. The final remarks of this study concluded that composites manufacturated with soils characterized by a higher plasticity index and reinforced with sheep wool fibres, developed a higher compressive strength due to water absorbtion of the fibres. This characteristic of fibres and the soil-fibre surface friction are dependent to the available water which depends on the soil plasticity. Higher strength of the material means smaller quantity of freely available water and smaller porosity, but not necessarily a weaker interaction among soil and fibres. For all types of tested soils, regardless their plasticity index, the authors observed that the sheep wool reinforcement decreased the shrinkage and increased the flexural strength of the specimens. They also noticed that a higher fibre proportion create difficulties to compacting the material, resulting a flexural and compressive strength decreasing.

Zagarella *et al*. (2014) developed a biocomposite concrete with a mineral matrix (lime) and sheep wool in different percentages and granulometries in the mixture, and a layered envelope system. The biocomposite concrete was made with sheep wool fibres cut to 4 and 6 mm length, lime (density = 564 kg/m^2), hydraulic lime (1,012 kg/m^2), and water. The content of sheep wool added in mixtures was by 20%, 30% and 40%. The thermal conductivity results improved with the sheep wool fibres content increasing: λ = 0.15 W/mk for a content of 20% fibres, λ = 0.13 W/mk for a content of 30% fibres, and λ = 0.11 W/mk for a content of 40% fibres. The reported values are too high for a proper insulation material, but these biocomposites still have a high mass that can improve the energy efficiency of a building.

Štirmer *et al*. (2014) developed a sheep wool composite with a cementitious matrix for wall coating purposes. The studied material was made by sheep wool fibres (in 3, 5, and 9% per mortar mass), cement, fine aggregates, water and admixtures (plasticizer, air entraining admixture, polymer and water retaining admixture). The reported results revealed that the thermal conductivity values of the mortars with 5% and 9% sheep wool fibres were with 26% and 54%, respectively, smaller than the reported values from literature for mortars with the same density, and with 19% and 36%, respectively, smaller than the reference mortar. But the benefits on the thermal conductivity direction were pulled down by the mechanical properties decreasing of investigated samples. Compressive strength decreased with more than 50% for the strongest mixture (with 3% sheep wool fibres per mortar mass), while the flexural strength decreased with about 30%. The ratio between compressive strength and flexural strength also decreased for samples with sheep wool up to about 2.7 (from 5, which was established for reference sample). The modulus of elasticity, capillary absorbtion and the adhesive strength of the sheep wool mortars were likewise reported going down. In conclusion, an obvious advantage highlighted by this report regarding the sheep wool composites reffers to the obtaining of mortars with a better insulation value than the reference one.

A quasi same conclusion about mechanical properties of a studied cementitious composite with sheep wool was drawn by Grădinaru *et al*. (2016). In their research, the authors investigated the compressive strength, and the flexural and splitting tensile strength on concrete made of 10% fly ash replacement from the cement quantity, cement, 0.125,...,16 mm aggregates, water, plasticizer and sheep wool fibres in two length variants (20-30 mm and 50-60 mm) and in two percentage variants (0.35% and 0.80% of total mass of concrete mix). In the case of 0.35% addition of the shortest fibres, the compressive strength, and flexural and split tensile strength decreased. On the other hand, a same percentage of the longest fibres increased the flexural strength, and had no influence on splitting strength. At the highest percentage of fibres addition, all the investigated mechanical properties decreased, no matter the length of used fibres.

In conclusion, mechanical properties of the cementitious composites decreased as result of sheep wool addition. One explanation of this effect can be the reaction sheep wool-alkaline fluids with pH higher than 11 (Štirmer *et al.*, 2014), such as the cement paste. This reaction involves the fibres swelling which results, after the composite drying, in very small air voids around the fibres and, subsequently, in smaller degree of friction and weakened bonding between these and the cementitious matrix.

5. Conclusions

In the sector of building constructions, natural fibres represent an alternative to synthetic materials, due to their renewability. Various studies proved:

1º Besides thermo-acoustical applications, natural fibres are increasingly used as reinforcement for different kind of composites in building industry.

2º Sheep wool shows good acoustical performances, being adequate as sound absorber in acoustic rooms, as noise barrier or as vibration insulator.

3º As a thermal insulator material, the sheep wool is characterized by a comparable thermal conductivity to glass wool and polystyrene foam.

4º Wool fibres are more hygroscopic than any other fibres. As a result of moisture content increasing, the thermal conductivity coefficient does not change significantly. Another advantage of its high ability to absorb moisture is the prevention of condensation, regulation of humidity and creation of a pleasant indoor atmosphere.

5º As a material for reinforced composites, sheep wool may be used *per se* or after some chemical treatments in order to improve its adherence to the polymeric matrix. Composites obtained from geo polymeric matrix and 5% Wt sheep wool fibres presented a homogeneous fibre distribution and an increasing of flexural strength and failure/fracture characteristics.

6º Composites manufacturated with soil and reinforced with sheep wool fibres, developed a higher compressive strength due to water absorbtion of the fibres; sheep wool reinforcement decreased the shrinkage and increased the flexural strength of the soil-sheep wool composites, the residual strength, the ductility and the energy absorbtion of the material after the first cracking. A higher fibre proportion create difficulties to compacting the material, resulting a flexural and compressive strength decreasing.

7º Mechanical properties of the sheep wool composites with a cementitious matrix decreased as result of sheep wool addition, but an advantage of these composites is the obtaining of materials with a better insulation value than the traditional ones.

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LÂNA DE OI – UN MATERIAL NATURAL UTILIZAT ÎN INGINERIA CIVILĂ

(Rezumat)

În ultimii ani, utilizarea fibrelor naturale a devenit din ce în ce mai întâlnită în domeniul ingineriei civile, ca parte a tendințelor către eficiență energetică şi sustenabilitate. În România, creşterea oilor reprezintă o activitate tradițională. Anual, sunt produse cantități însemnate de lână ce sunt tratate ca deşeuri, fiind arse sau îngropate. O serie de cercetări au demonstrate bunele proprietăți ale fibrelor de lână ce le recomandă să fie utilizate ca material isolator sau în armarea compozitelor.

Scopul acestei lucrări este de a evidenția posibilitățile de utilizare a lânii de oi ca material de construcție. Acest studio este important întrucât, în present, cunoaşterea şi aplicarea fibrelor de lână în acest sector sunt relative limitate şi tratate cu incertitudine.