# CEMENT COMPOSITES REINFORCED WITH SHEEP’S WOOL

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## Abstract

Sustainability issues have become prevalent in the past years especially in sustainable construction practices which are both ecologically friendly and also cost efficient as they are often based on the utilization of available end-of-life materials.

This paper describes a research on the use of a new construction material composed of cement and natural fibres obtained from sheep’s wool.

Low grade sheep wool has no use and needs to be disposed of and that costs money together with several serious problems created by its safe utilization. There are about 90 million sheep in the EU, producing 270.000- tons of wool. An estimated 10% is low grade coarse wool and needs to be disposed.

Within presented research, sheep’s wool is utilized in cement and lime based mortar mixtures to be used for rendering of interior wall surfaces. The aim of the research was to experimentally quantify and to compare the performance of natural sheep’s wool fibres in low strength mortar.

Developing a mortar mix design enhanced through the addition of natural sheep’s wool fibres, together with quantifying and analysing mechanical, physical and thermal properties of such cement and lime based mortar are the topics of this research.

## 1. INTRODUCTION

Sheep wool is natural material used in civil engineering for both thermal and acoustic insulating applications. It is used as well for façade insulation as for roof insulation [1]. According to available literature [2], there are a small number of investigations of the sheep wool as addition in mineral composites. Also, sheep wool is not always adequately disposed or recycled [3]. Approximately 80 % of the global sheep wool production is intended to be used in the textile industry. However, existing sheep wool in Croatia and neighbouring countries is not suitable for application in the textile industry. Properties of the wool depend on its chemical composition and complex protein structure. In its natural state, raw wool from sheep contains a number of constituents other than the fibre. The main ones are wool grease, water-soluble material derived from perspiration and contaminants such as dirt and vegetable matter which can be removed by washing. Clean wool belongs to a group of proteins known as keratins. It has been estimated that wool contains more than 170 different proteins not uniformly distributed throughout the fibre [4]. This heterogeneous composition is responsible for different physical and chemical properties of the various regions of wool. The proteins in wool are composed of amino acids. A wool fibre can be considered as a biological composite consisting of regions that are both chemically and physically different. Even after the natural wool grease has been removed by scouring with a detergent, wool fibres are relatively difficult to wet compared with other textile materials. This natural water repellency makes wool fabrics 'shower-proof ' and this property is the result of a waxy, hydrocarbon coating that is chemically bound to the surface. The first step in wool processing, regardless of the end product, is washing in hot, soapy water (i.e. scoured) to remove dirt, grease and other impurities. The scouring water is normally about 65ºC, which is hot enough to dissolve the wax (i.e. lanolin), and detergent is added to help remove the dirt from the fibres and to emulsify the wax so it doesn’t stick back onto them. This stage is also the stage where the chemical agents (according to the end usage) are applied to the wool [1]. Clean wool contains 82% of the keratinous proteins, which contain high concentration of sulphur (3%). The amount of sulphur in the keratin determines the strength of wool because of strong disulfide bonds. Keratin does not dissolve in cold or hot water and does not breakdown into soluble substances.

This research intends to contribute to the management and reuse of sheep wool waste in order to reduce their impact on the environment. The study is focused on the possibility of using sheep wool fibres in the production of mortar, i.e. composites made of cement, fine aggregates, water and eventually admixtures and additions, particularly for use as wall coatings. Classification for hardened mortar properties according to HRN EN 998-1 is shown in Table 1.

Table 1: Classification for hardened mortar properties [5] according to HRN EN 998-1

| Property | Categories | Values |
|---|---|---|
| Compressive strength at 28 days | CS I | 0.4 – 2.5 N/mm$^2$ |
| | CS II | 1.5– 5.0 N/mm$^2$ |
| | CS III | 3.5 – 7.5 N/mm$^2$ |
| | CS IV | $\geq$ 6,0 N/mm$^2$ |
| Capillary water absorption | W0 | Not specified |
| | W1 | $c \leq 0.40$ kg/m$^2$min$^{1/2}$ |
| | W2 | $c \leq 0.20$ kg/m$^2$min$^{1/2}$ |
| Thermal conductivity | T1 | ≤ 0.1 W/mK |
| | T2 | ≤ 0.2 W/mK |

## 2. EXPERIMENTAL PART

In the experimental part, different mortar mixtures were prepared (Figure 1) on which an analysis of mechanical, physical and thermal properties was performed (Table 1). All mixtures were prepared with Portland cement CEM IIB-M S-V 42.5N, crushed sand 0/4 mm, lime, expanded clay, metakaolin and chemical admixtures: plasticizer, air entraining admixture, polymer and water retaining admixture. Totally, four mixtures were produced, the first was considered as the reference (REF). Other three mixtures SW3, SW5 and SW9 were produced by adding sheep wool fibres in amount of 3, 5 and 9 % per mortar mass, respectively. First step was to prepare sheep wool fibres of required length (Figure 1a). Before that, wool was washed and cut to appropriate length.

a) b)

Figure 1: Sheep wool fibres and preparation of mortar

Table 1: Tested properties

| Property | Test method |
|---|---|
| Consistence of fresh mortars (by flow table) | HRN EN 1015-3:2000/A2:2008 |
| Compressive strength | HRN EN 1015-11:2000/A1:2008 |
| Flexural strength | HRN EN 1015-11:2000/A1:2008 |
| Modulus of elasticity | HRN EN 13412:2007 |
| Water absorption coefficient | HRN EN 1015-18:2003 |
| Adhesive strength | HRN EN 1015-12:2000 |
| Thermal conductivity | HRN EN 1745:2012 |
| Shrinkage | HRN EN 12617-4:2003 |

## 3. RESULTS OF TESTING

### 3.1 Results of testing fresh mortar

Results of testing fresh mortar are shown in the Table 2. Water was added individually for each mixture so as to achieve minimum consistency of 140 mm (Figure 2).

Figure 2: Fresh mortar with wool fibres and testing of consistence (flow table)

Table 2: Properties of the fresh mortar

| Mortar mixture | Consistence (by flow table) (mm) | Mixing water needed to achieve target workability (ml/dm$^3$) | Mortar temperature (°C) | Density (kg/dm$^3$) | Air content (%) |
|---|---|---|---|---|---|
| REF | 153 | 194.3 | 22.0 | 1.49 | 27 |
| SW3 | 148 | 219.2 | 23.4 | 1.37 | 30 |
| SW5 | 150 | 287.4 | 22.4 | 1.12 | 40 |
| SW9 | 143 | 488.4 | 22.0 | 1.09 | 34 |

### 3.2 Mechanical and physical properties

Flexural strength of mortars was determined using 40x40x160 mm prisms which were tested at the age 28 days. The compressive strength of the mortars was determined using portions of the prismatic specimens made and broken in the flexure test (Figure 3a). Modulus of elasticity in compression was also tested 40x40x160 mm prisms (Figure 3b).

a) b)

Figure 3: Testing of mechanical properties

For adhesive strength testing, concrete panels with dimensions 550 x 550 x 50 mm were used. The fresh mortar was applied to the concrete substrate in a thickness of 20 mm. Individual testing results are shown in the Figure 4. During testing, two types of fracture pattern have appeared: fracture within the mortar and fracture at the interface between the mortar and substrate. Mean values are shown in the Table 4.

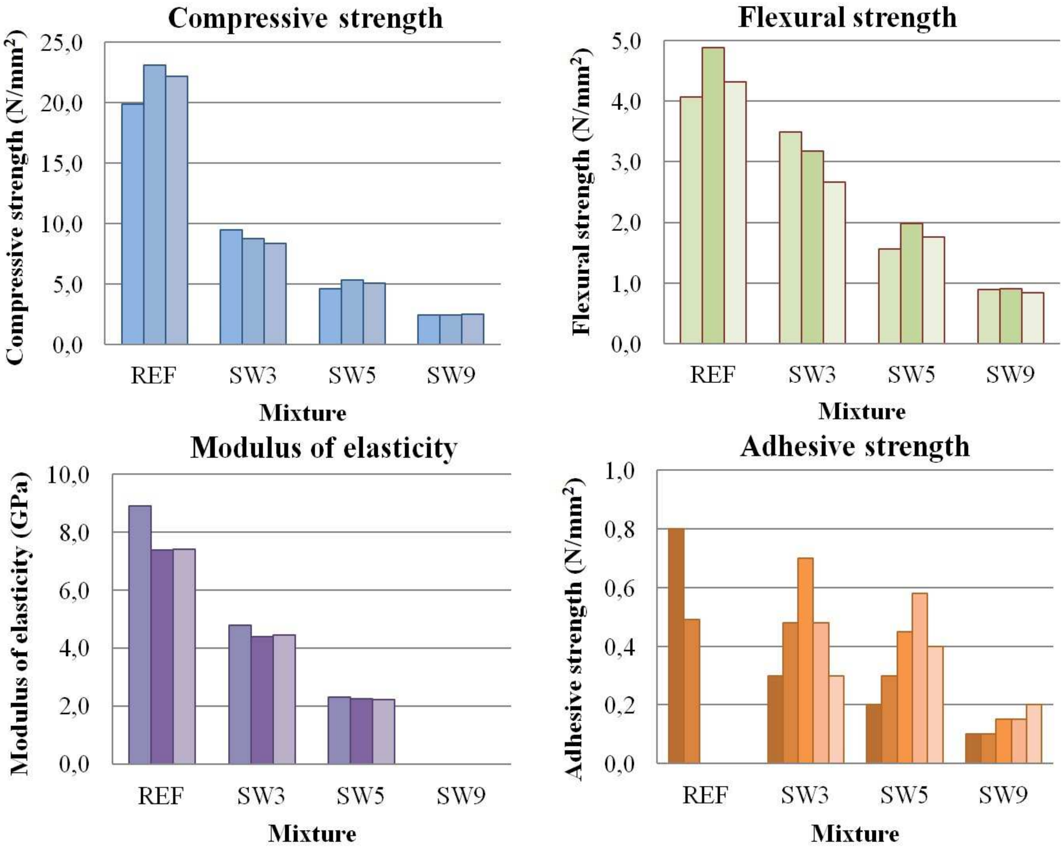

Figure 4: Results of testing mechanical properties

Based on the compressive strengths, mortar SW3, SW5 and SW9 can be classified as CS IV, CS III and CS II, respectively, according to Table 1. As already mentioned, during the adhesive strength test, the fracture occurred through mortar itself and can thus be concluded that the adhesive strength is greater than the test values. It is widely accepted in the literature that for the plastering/rendering mortar, the adhesive strength test should generate a crack in the plaster/rendering base, or the adhesive strength must be greater than 0.1 N/mm$^2$ [5]. This requirement is satisfied for mixtures SW3 and SW5, while SW9 results are borderline satisfactory. The Young's modulus of the mortar should be smaller than that of the surface to be treated [5] which can be easily satisfied for large number of different surfaces with fairly low modulus measured for SW3 and SW5.

Capillary water absorption (HRN EN 1015-18: 2003) was also measured in order to better characterize the most common property of the plasters. The water absorption coefficient due to capillary action is measured using mortar prism specimens with dimensions 160x40x40 mm under prescribed conditions. After drying to constant mass, one face of the specimen is immersed in 5 to 10 mm of water for a specific period of time and the increase in mass is determined. The coefficient of water absorption is by definition equal to the slope of the straight line linking the representative points of the measurements carried out at 10 min and 90 min. and it is calculated according to the formula given in the standard. For each mixture, 3 specimens were tested and mean coefficients of water absorption are shown in the Table 4. It can be seen from the water absorption results that according to Table 1 mortars can be classified as W2 (SW3, SW5), while SW9 falls into W0 category, but is smaller than the required 0.5 $kg/m^2h^{0.5}$ [5].

### 3.3 Thermal properties

Testing of thermal conductivity was carried out according to HRN EN 12667:2002 and HRN ISO 8302:1998. Among the steady state methods for determining thermal conductivity, the guarded hot plate (GHP) is the most commonly used technique for measuring the thermal conductivity of materials. GHP can be regarded as absolute measurement method, because by measuring the temperature, power of electric energy and thickness, thermal conductivity can be calculated. In principle, its operation is based on establishing a steady temperature gradient over a known thickness of a sample and to control the heat flow from one side to the other. Thermal conductivity was determined by the determination of thermal resistance by means of GHP and the known thickness of the specimens used. Results of testing thermal conductivity are shown in the table 3.

Table 3: Results of testing thermal conductivity

| Mortar mixture | Thickness, mm | Density of hardened mortar, $kg/m^3$ | Thermal conductivity, W/mK |
|---|---|---|---|
| REF | 47.6 | 1241 | 0.274 |
| SW5 | 50.6 | 953.4 | 0.222 |
| SW9 | 53.5 | 856.8 | 0.175 |

The literature values of thermal conductivity of mortar vary significantly, depending on the type of aggregates used, temperature and moisture content of mortar, together with its density and the content of lime. For the mortar density of 700 $kg/m^3$, 1000 $kg/m^3$ and 1500 $kg/m^3$, HRN EN 1745 [6] gives thermal conductivities of 0.20 W/mK, 0.30 W/mK and 0.54 W/mK, respectively for dry masonry mortar and rendering mortar, while [7] gives thermal conductivity of 0.38 W/mK and 0.25 W/mK for the lightweight mortar with the density of less than 1000 $kg/m^3$ and 700 $kg/m^3$, respectively.

It can thus be concluded that the mortar containing sheep wool SW5 and SW 9 have 26 % - 54 % lower thermal conductivities than the reported literature values for the mortar of the same density range. It has to be noted here, that reference mortar which has the same composition but without the sheep wool has 19 % and 36 % higher thermal conductivity than SW5 and SW9 mortars, respectively.

### 3.4 Shrinkage

Shrinkage and swelling deformations of the mortars are determined according to HRN EN 12617-4. From the results shown in the Figure 5, it can be seen that all three mixtures with sheep wool fibres swell at the beginning. It can be explained by chemical reactivity of the wool i.e. the wool swells in alkaline fluids with pH higher than 11. In this research, up to 28 days, no damage was observed on the specimens. However, this could limit possible application of these mortars, because wool can be dissolved in alkalis [1].

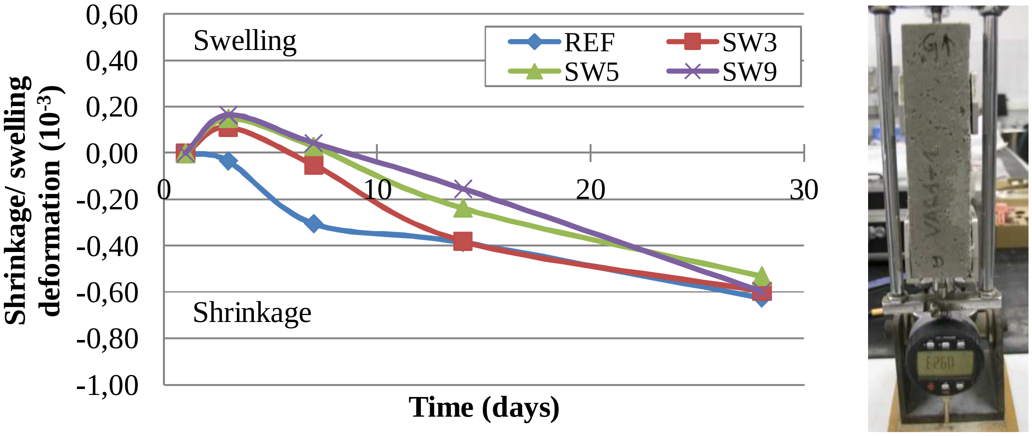

Figure 5: Results of testing shrinkage/ swelling of mortar mixtures

## 4. ANALYSIS

From the results of testing shown in the Table 4, it can be concluded that addition of sheep wool fibres reduces density and generally improves thermal insulation properties but at the same time decreases mechanical properties. Table 3 shows lower values of flexural strength of all mortars made with sheep wool fibres than that of the reference mix (REF). However, ratio between compressive and flexural strength for mixtures SW3, SW5 and SW9 is approximately 2.7, while for reference mixture, it is 5.

Table 4: Results of testing mortars with sheep's wool and reference mortar

| Property | Mixture | | | |
|---|---|---|---|---|
| | REF | SW3 | SW5 | SW9 |
| Sheep wool fibres (% per mass of mortar) | - | 3 | 5 | 9 |
| Density of hardened mortar (kg/dm$^3$) | 1.52 | 1.29 | 1.08 | 1.02 |
| Compressive strength at 28 days (N/mm$^2$) | 22.2 | 8.7 | 5.1 | 2.4 |
| Flexural strength at 28 days (N/mm$^2$) | 4.4 | 3.1 | 1.8 | 0.9 |
| Modulus of elasticity at 28 days (N/mm$^2$) | 7892 | 4535 | 2249 | - |
| Capillary absorption at 28 days kg/(m$^2$min$^{0.5}$) | 0.004 | 0.153 | 0.145 | 0.482 |
| Adhesive strength at 28 days (N/mm$^2$) | 0.65 | 0.45 | 0.39 | 0.14 |
| Thermal conductivity, W/mK | 0.274 | - | 0.222 | 0.175 |

## 5. CONCLUSION

- In this work, the possibility of using environmentally-friendly mortars produced with sheep wool fibres was studied. The effect of fibre volume fraction on mortar content, properties such as compressive strength, flexural performance, thermal insulation and density have been determined.
- Mortars up to 5 % sheep wool fibres proved to have better workability, smaller capillary absorption and better mechanical properties than mortar with 9 % fibres. The total water content in the mortars with 9 % fibres was substantially higher than that in the reference mix, for the same workability. Thermal conductivity has shown a promising opportunity for sheep wool fibres, because these mortars attained good insulation value compared to the mortars without the sheep wool fibre. Reaction of the wool with alkalis limits application of the sheep wool fibres in cement composites.
- Based on the results obtained, mortars with sheep wool fibres could be used for repair of historical buildings where properties should be similar to original mortar. Decreased density with increase of fibre volume fraction will make it a better material with less weight and good performance for example as false ceiling tile and non load bearing wall partitioning.

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