Bulletin of the *Transilvania* University of Braşov • Vol. 9 (58) - 2016
Series I: Engineering Sciences

INVESTIGATIONS ON THE MECHANICAL PROPERTIES OF CONCRETE WITH SHEEP WOOL FIBERS AND FLY ASH

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Abstract: *The aim of this paper was to investigate the influence of sheep wool fibers (SWF) and fly ash (FA) on the compressive and tensile strength of concrete. There were prepared seven types of mixes, including one reference mix without any addition and for the others, a part with SWF only, and a part with SWF and FA addition. The tests were performed to determine compressive strength and flexural and split tensile strength of the concrete mixes. The experimental results showed that SWF did not improve, overall, the strength of the concrete at the studied percentages of addition and, more than that, in the most of the cases, resulted lower strength.*

Key words: *sheep wool, fly ash, natural fibers, wastes.*

1. Introduction

The cement industry is responsible for 5-7% of worldwide CO_2 emissions. In order to reduce them, new building materials have been developed as a part of the new tendencies for eco-materials obtaining and protection of natural resources [2].

The use of different wastes in the concrete mix developed a new type of construction materials concept: *green materials*. These are „*green”* not in their color but in their manufacturing, being ecological due to the wastes introduced as powder or filler or as aggregates *(for example, concrete or bricks from demolition, steel slag etc.).* In the same time, there are many years since the cement industry has incorporated significant quantities of wastes, such as silica fume, fly ash, blast furnace slag, cinder, metakaolin, ceramic waste, husk, tires, glass etc. due to energetic, economic and environmental protection conveniences [17].

Even though the ingredients for the concrete manufacture are available almost everywhere, there could be opportunities to use some local wastes which have appropriate characteristics for concrete production [12].

Until now, many admixtures were used to increase the concrete properties and to reduce environmental pollution [3]. As an example, a 15-35% replacement of the cement quantity from the concrete with FA result in higher strength, a better behaviour

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to sulfate action, lower permeability, a decreased quantity of required water and a better workability [1].

The concretes with pozzolanic admixtures are intense studied because it is needed to obtain some high performant materials and to use some industrial sub-products [7]. Geopolymeric concretes (with FA or slag) can be an option to reduce CO_2 emissions with 40-95% [5], [13].

FA is a residue from power plants or from different processes of incineration of solid materials. In our area annually resulted around 21740 tons of *ashes (fly and bottom ashes).* In the last twenty years resulted approximately 500 million tons of FA, from which just a small part is capitalized, the unused FA being on the landfills [6],[8],[10].

Its principal properties are gray-black color, spherical particles formed mainly of silicon dioxide, specific area 480–520 m^2/kg and density of 2400–2550 kg/m^3. The residues from coal burning contain 80% FA and 20% bottom ash. Physical and chemical properties of the FA are different from a thermal plant to another. Replacing a part of the cement with FA have some advantages, like a high level quantity of cement replaced *(an optimum level of replacing is 30%),* an improved durability *(less heat of hydration emitted),* improved workability of the concrete [6],[9],[15].

Experimental studies on cement concrete with FA shown that the addition of fiber, near FA is beneficial in improving the properties [4]. FA pozzolanic reaction from concrete depends on chemical composition of the FA and Portland cement, particle morphology, their finess and the emitted heat of hydration [7].

FA produces environmental damage by causing air and water pollution on a large scale while the cost of storage of this waste is very high. The most serious problem is the hazard to atmosphere and underground water quality which would be a potential risk to the health and property of citizens and cause a huge stress to the economic and environmental system [10].

Another source of FA waste is from the solid waste incineration technology which is used in big cities of the world because its effectiveness in volume, weight and toxicity reduction, and also in energy and resource conservation.

The municipal solid waste incineration FA can be used as raw material in sintering and preparing calcium sulphoaluminate cement, which had similar properties as the conventional cement [14].

Wastes of fibers of different types *(glass, polypropylene fiber, carbon, polyester, textile etc.)* and length are used to obtain concrete with disperse reinforcement. Since ancient times straw and horsehair were used to reinforce sun-baked bricks or masonry mortar and plaster.

The properties of fiber reinforced concrete depend on the fiber type, the geometry, the percentage of fiber, orientation and distribution of fiber, mixing and compaction of concrete.

The various applications of fiber reinforced concrete such as shotcrete in underground works, precast products, architectural panels, hydraulic constructions etc. had contributed to the rapid development of this new building material [4].

The natural fiber use means low cost, reduced processing level, are eco friendly and the most important, some of the natural fibers can have the same strength like the synthetic ones [16].

Low grade *sheep wool* has no use and needs to be disposed of and this cost money. In European Union there are about 90 million sheep that produce 270.000 tons of wool. An estimated 10% of this is low grade coarse wool that needs to be disposed. Few researches of cement composites with sheep wool were done until now [16].

The aim of natural fibers use is, mainly, to reinforce the concrete to ensure a better tensile strength, ductility and post-cracking behaviour. The inclusion of fibers can enhance also the fracture toughness, flexural strength, resistance to fatigue, impact, thermal shock and spalling of the concrete [11].

The aim of the paper is to investigate the influence of SWF and FA on the compressive and tensile strength of concrete. This paper is a start point from a serie of researches using local resourses, being important because were done few researches with the local resources until now and it is needed for an alternative solution to use this kind of wastes for a healthier environment.

2. Experimental Protocol

In order to test the compressive and tensile strength, the experimental protocol including seven mixes of concrete was applied, with the respect of actual norms in Romania [19-21].

There were used the following materials:

- *river aggregates, with maximum granule size of 16 mm;*
- *cement type CEM II, with mineral additives and strength of 42.5R MPa[22], produced in Romania;*
- *FA from CET Holboca Iasi.*
- *SWF from Ţurcana, a Romanian breed.*

The test samples were cube molds with *150 mm* on sides and *100x100x500 mm* prism molds, three samples for each mix, which were kept in standard conditions 28 days before testing.

3. Materials and Methods

The experimental study was carried out on cement concrete with FA and SWF. In order to prepare the concrete, the following raw materials were used: cement and FA as a filling agent, river aggregate and gravel and SWF. The cement was CEM II 42.5 type, which is a Portland cement produced in Romania [22].

The FA was from the Holboca Thermal Power Plant, Iasi County, Romania.

Different lengths of SWF were introduced into the concrete mix in two different dosages. *SWF were collected from Ţurcana breed* .The fiber percentages were *0.35% and 0.80%* of the concrete weight. The fiber length was around *25 mm* and *55 mm.*

The aggregate was a type of natural sand *(diameter 0–4mm)* and river gravel, diameters of *4–8 mm* and *8–16 mm.*

To improve the workability of the concrete compositions, a polycarboxylate ether superplasticizer type Viscocrete-1040® (manufactured by Sika Group) was added to the mixtures.

Experimental Samples

In this research, seven concrete mixes were manufacturated, from which one was the reference concrete mix done with cement, sand, different sorts of natural rounded aggregates smaller than *16 mm* and superplasticizer admixture. For comparative study of the concrete properties with additions, 10% of cement quantity was replaced with FA and SWF in two lengths *(20-30 mm* and *50-60 mm)* and two mass percentages *(0,35% and 0,8% of total mass of concrete mix)* were added. Thus, the following concrete mixes were realised:

1) *RCM - reference concrete mix (with no addition);*
2) *SSC 0.35% - short sheep wool concrete (with 0.35% SWF of 20-30 mm length);*
3) *LSC 0.35% - long sheep wool concrete (with 0.35% SWF of 50-60 mm length);*

4) *SSC 0.80% - short sheep wool concrete (with 0.80% SWF of 20-30 mm length);*
5) *LSC 0.80% - long sheep wool concrete (with 0.35% SWF of 50-60 mm length);*
6) *SSCFA 0.80% - short sheep wool concrete with FA (with 0.80% SWF of 20-30 mm length);*
7) *LSCFA 0.80% - long sheep wool concrete with FA (with 0.35% SWF of 50-60 mm length).*

The reference concrete mix was C25/30 grade: cement *360 kg/m3,* sort I (*0–4 mm)* in a quantity of *803.16* kg/m^3, sort II *(4–8 mm)* in a quantity of *384.12* kg/m^3, sort *III (8–16 mm*) in a quantity of *558.72* kg/m^3, water *180* L/m^3, and superplasticizer type Sika ViscoCrete-1040® in a dosage of 1.3% of the binder weight.

A water/binder ratio of 0.5, 0.55 and 0.65 was used for the reference concrete mix, concrete mixes with 0.35% SWF and concrete mixes with 0.80% SWF, respectively. Different water/binder ratios were needed to ensure an appropiate level of concrete workability *(SWF absorbed a suplementary quantity of water).*

The concrete was prepared in a 1.0 m^3 mixer by mixing the aggregates with cement, FA, water and superplasticizer; before the final mixing, the fibers were introduced into the fresh mix. The concrete was poured into cube molds of *150x150x150 mm* and prism molds of *100 × 100 ×500 mm* and kept in water for 7 days and under laboratory conditions at 20^0C until 28 days.

The samples were tested for compressive strength, flexural and split tensile strength, according to SR EN 12390-3:2009/ AC:2011, SR EN 12390-5:2009 and SR EN 12390-6:2010.

3. Results and discussions

The results regarding mechanical properties of RCM, SSC 0.35% and LSC 0.35% are presented in Figures 1and 2.

As it is presented in Figure 1, the short sheep wool *0.35%* addition resulted in flexural and split tensile strength decreasing with *47.92*% and *72.25*%, respectively, compared to *RCM.* The double length of SWF determined instead the increase of flexural tensile strength with *7.30 %* and mantained the split tensile strength at the same value.

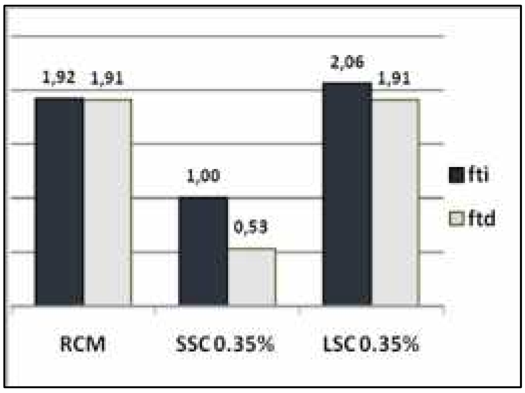

Fig. 1. *Mechanical properties of RCM, SSC 0.35% and LSC 0.35% - flexural* (f_{ti}) *and splitting* (f_{td}) *tensile strength [N/mm²]*

As regard to the compressive strength *(Figure 2)*, SWF 0.35% addition led to 28.14% smaller values than those of *RCM*, while the long fibers had an insignifiant influence.

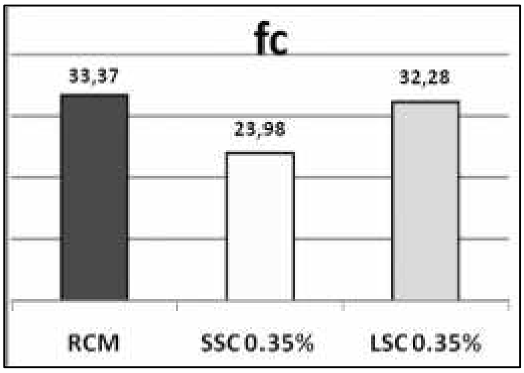

Fig. 2. *Mechanical properties of RCM, SSC 0.35% and LSC 0.35% - compressive strength [N/mm^2]*

In *Figures 3 and 4*, are presented the mechanical properties of *RCM,* SSC 0.80%, LSC 0.80%, SSCFA 0.80% and LSCFA 0.80%.

To a higher quantity of SWF up to the limit of obtaining an acceptable workability of the material (0.80% of the total mass of concrete), the concrete performances decreased, both in terms of compressive strength (Figure 3) and flexural and split tensile strength *(*Figure 4*).*

Compressive strength diminished with around 60% (Figure 4), flexural tensile strength with 22%, and split tensile strength with 30% and 45% in case of SSC 0.80% and LSC 0.80%, respectively, compared to values for RCM (Figure 3). By replacing 10% of cement quantity with FA, flexural tensile strength had the same low values, without significant differences. SSCFA 0.80% mix had the smallest value for the split tensile strength (Figure 3).

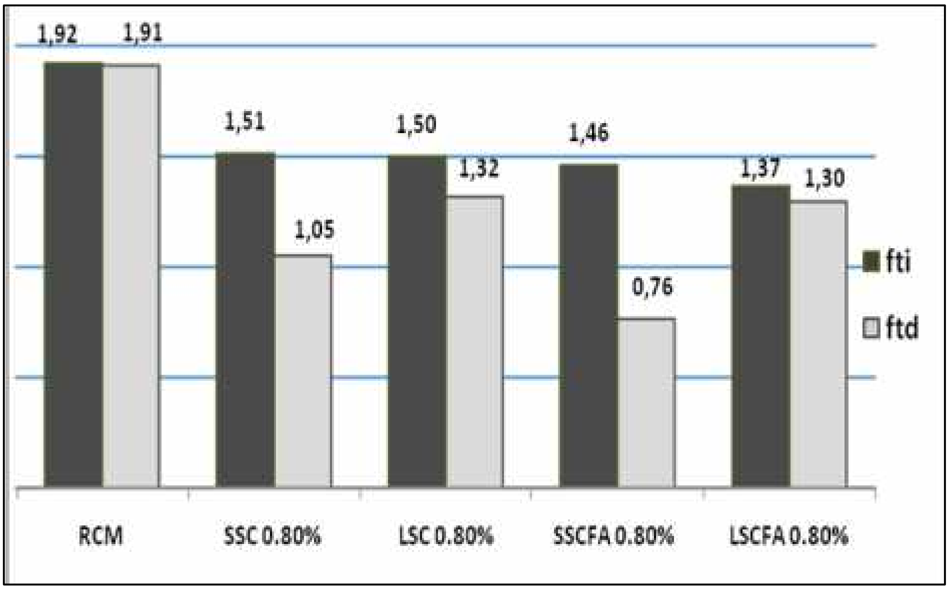

Fig. 3. *Mechanical properties of RCM, SSC 0.80%, LSC 0.80%, SSCFA 0.80% and LSCFA 0.80% - tensile strength [N/mm^2]*

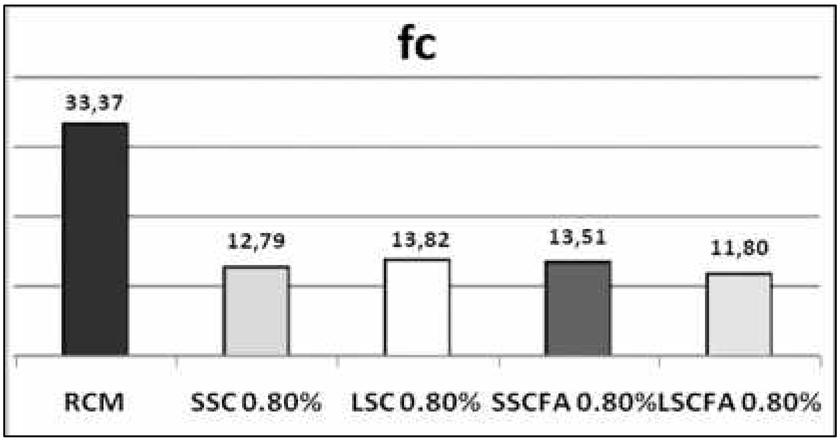

Fig. 4. *Mechanical properties of RCM, SSC 0.80%, LSC 0.80%, SSCFA 0.80% and LSCFA 0.80% - compressive strength [N/mm^2]*

In conclusion, SWF did not improve the strength of the concrete at this percentage of addition and, more than that, in the most of the studied mixes, resulted lower strength; many fibres extended across cracks at angles other than 90^{o}C or may have less than the required embedment length for development of adequate bond. Therefore, only a small percentage of the fiber content may be efficient in resisting tensile or flexural stresses. The efficiency factor depends on fiber length and critical embedment length.

Another possible reason for the results obtained can be the suplementary quantity of water added to the concrete mixes, compared to the RCM, this contributing to the decrease of the concrete strength.

The mixture composition of fiber reinforced cementitious materials is a compromise between acceptable workability and improved efficiency in the hardened state. The fiber content of a concrete that is still workable depends on the mixture composition and the fibre type. Fibers tend, moreover, to "ball" in the mix which again creates workability problems and limit the level of addition. Using equipment with worn-out mixing blades is yet other cause of fiber balling. Processing the concrete so that the fibers become aligned in the direction of applied stress will result in greater tensile or flexural strengths. The reinforcing ability of the fibers depends on how the fibrers are dispersed throughout the material. Poorly dispersed fibers provide little or no reinforcement in some regions, which then act as flaws in the composite material.

4. Conclusions

This study focused on characterizing cement concrete containing SWF and FA. FA was used to replace a part of cement and SWF were added to improve the mechanical properties, especially the tensile strength.

SWF did not improve, overall, the strength of the concrete at the studied percentages of addition and, more than that, in the most of the cases, resulted lower strength:

- the short SWF *0.35%* addition resulted in flexural and split tensile strength decreasing with *47.92*% and *72.25*%, respectively, compared to *RCM;*
- the long SWF determined the increase of flexural tensile strength with *7.30 %* and

mantained at the same value the split tensile strength;

- short SWF 0.35% addition led to 28.14% smaller values for compressive strength than those of *RCM*, while the long fibers had an insignifiant influence;
- to a higher quantity of SWF up to the limit of obtaining an acceptable workability of the material (0.80% of the total mass of concrete), the concrete performances decreased, both in terms of compressive strength and flexural and split tensile strength, a possible reason for these results can be the suplementary quantity of water added to the concrete mixes, compared to the RCM.

Researches are far to satisfy the needed studies from this domain and for this reason new studies are necessary to find new methods to control the fiber dispersion in the concrete and the fibers become aligned in the direction of applied stress to result in greater tensile or flexural strengths and to adjust the mixture composition by increasing the content of grains that are relatively small to the fiber length to compensate for the effect of the fibers.

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