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STUDY ON THE INFLUENCE OF CHOPPED CARBON FIBRE REINFORCEMENTS ON THE BEHAVIOUR OF CEMENTITIOUS COMPOSITES

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Abstract: *Cementitious building materials in general or mortars in particular, require reinforcement due to their brittle behaviour, poor tensile strength or strain capacities. Randomly distributed fibres in a cement-based matrix (traditional mortar or concrete) lead to the improvement in the strength and energy absorption capacity of the composite. This paper investigates the influence of carbon fibres as reinforcement on cementitious mortar matrices (CFRM) and bring out the composite principal mechanical properties such as compression and flexural strength. The CFRM properties were compared to the plain, unreinforced mortar.*

Key words: *cementitious materials, fibre-reinforced mortar, carbon fibre, tensile strength, composite materials.*

1. Introduction

An alternative of continuous reinforcing bars in case of moderated loads is to incorporate randomly orientated and distributed discontinuous short fibres in the cement-based matrices.

The idea is not a new one; the composition of the construction materials was improved since ancient times, even using natural fibres or natural polymers. One of the earliest uses of fibre-reinforced composites was in the ancient times by Mesopotamians and Egyptians.

Since the time of Pharaohs in Egypt and during that time period, the principal building material was clay, used in the construction of housing walls and later in the form of bricks in admixture with waste vegetables and reinforced with straw. [4]

New requirements in the field of construction materials and civil engineering led to the revival of the concept and application of these materials, which has been the subject of intense development in several areas to this day.

Nowadays, it is also well known that the addition of a relatively small quantity of short random fibres to a cementitious matrix improves the mechanical response of the resulting product, commonly known as a fibre-reinforced cementitious composite (FRCC). FRCCs have the potential of exhibiting higher strength and ductility in comparison to unreinforced mortar or concrete, which fail in tension immediately after the formation of a single crack. [5]

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The morphology of this composite leads to better behaviour at controlling cracking, and the fibres form a “bridge” across them. This property and behaviour of the FRCCs helps increase the capacity of the energy absorption as well.

The carbon fibres (CFs), having high tensile strength and good compatibility with cementitious materials, used together with this kind of matrix, form an example of a new and high-performance material in concrete technologies which continues to gain popularity in civil engineering applications.

About thirty years ago, carbon fibre was heralded as the new wonder material. However, carbon fibre was certainly not new, although it has since proved to be an extremely useful reinforcement material. Thomas Alva Edison turned his attentions to the incandescent electric lamp and in 1880 and patented the use of carbon fibre as filament material for his electric lamp. [3]

Carbon fibres are a synthetic fibre that has a micro-graphite crystal structure. It typically has a diameter of a few microns and is made using a high-temperature treatment process from a precursor material such as polyacrylonitrile (PAN), rayon and pitch. [1]

The most common carbon fibres are PAN-based which have good strength and modulus properties, whereas pitch-based carbon fibres can be made with a higher modulus, albeit with a lower strength. [3]

CFs have high tensile strength, stiffness, chemical resistance and temperature tolerance combined with low weight and thermal expansion. These properties make carbon fibres very popular in many engineering applications.

Due to the fact that fibres provide strength and stiffness and the matrix maintaining their alignment and transferring the loads to the fibres, the property improvements of the FRCCs in general, depend largely on the inclusions’ dispersion in the matrix.

Typical properties of carbon fibres by precursor material are given in Table 1.

Carbon fibres properties Table 1.

Precursor polymer	**Density** [kg/m^3]	**Tensile strength** [MPa]	**Elastic modulus** [GPa]
Rayon	1350 – 1450	660 – 820	34 – 41
PAN	1750 – 1870	900 – 6370	40 – 588
Pitch	1900 – 2200	1380 – 4050	159 – 966

2. Experimental Program

2.1. Components and Materials

In order to highlight the effects of short carbon fibres on the behaviour of cement-based mortar in terms of flexural and compressive strength, experimental programs and laboratory tests were carried out on specimens with and without carbon fibres (plain mortar). The experimental investigation is focused especially on flexural strength response of the composites.

The raw materials used to prepare the mixtures were “Structo Plus” CEM II/B-M (S-LL) 42.5 R cement with 42.5 MPa of compressive strength at 28 days, produced by Holcim Romania, natural sand with 0-4 mm granularity, water and short carbon fibre in case of the reinforced mortar recipe.

CEM II/B-M (S-LL) 42.5 R is a Portland composite cement with high initial strength. The main constituents are: Portland clinker (K) (65-79%) and an admixture of granulated blast furnace slag (S) and limestone (L), totalling 21-35% according to [2].

The carbon fibres used in this study are available commercially in China, U.S.A and Europe. They are made and sized by chopping (chopped carbon fibres) with filaments of a diameter of 7.0 μm and a length of 6 mm. Their properties and appearance are given in Table 2 and in Figure 1, respectively. The fibre content for this investigation was established at 3 kg/m^3.

Fig. 1. *Chopped carbon fibres used in the research with 6 mm length. Normal and close-up (macro) photos.*

Chopped carbon fibres properties Table 2.

Filament diameter [μm]	**Density** [g/cm^3]	**Tensile strength** [GPa]	**Elastic modulus** [GPa]	**Elongation** [%]
7.0	1.6 – 1.76	3.6 – 3.8	220 – 240	1.5

2.2. Methods of Mortar Manufacturing

A classical method of manufacturing was used for the mortar recipes in this research with a water/binder ratio of 0.5 and a cement/sand ratio of 1:3. The details of the proportion and composition of mortar mixes are given in Table 3.

Mortar recipes for 4.5 l mixture Table 3.

Recipes	**Cement** [g]	**Sand** [g]	**Water** [ml]	**Fibre** [g]
R1	2838.3	8514.8	1650	0
R2	2838.3	8514.8	1650	13.5

The mortar specimens were made according to current standards which entailed measuring (weighing) the materials, homogenizing with a mixer, and casting them in specific moulds.

All dry raw materials were mixed for 2 minutes, and water was added to form the plain mortar used as a control sample and as the matrix for the FRCC. In case of the FRCC, the fibres were added and dispersed into the mortar mixture and stirred for another 2 minutes.

The specimens were made in steel prism moulds of size 40 mm×40 mm×160 mm, shown in Figure 2 [6]. Four prism specimens per each mixture were used for flexure tests.

Fig. 2. *The steel prism moulds (a) and the humidified full bricks with ~10 mm mortar layer used for test the adhesion of hardened mortar to the substrate (b).*

2.2. Testing Procedures and Mechanical Investigations

The mechanical investigations were performed at 28 days on the previously-described specimens, then cast and stored according to the current standards.

The prism specimens and the remnants of the specimens were tested for flexural strength and compressions, respectively at the age of 28 days. All tests were performed with the equipment of the Laboratory of the Civil Engineering Faculty of Cluj-Napoca, according to the current standards and shown in Figure 3.

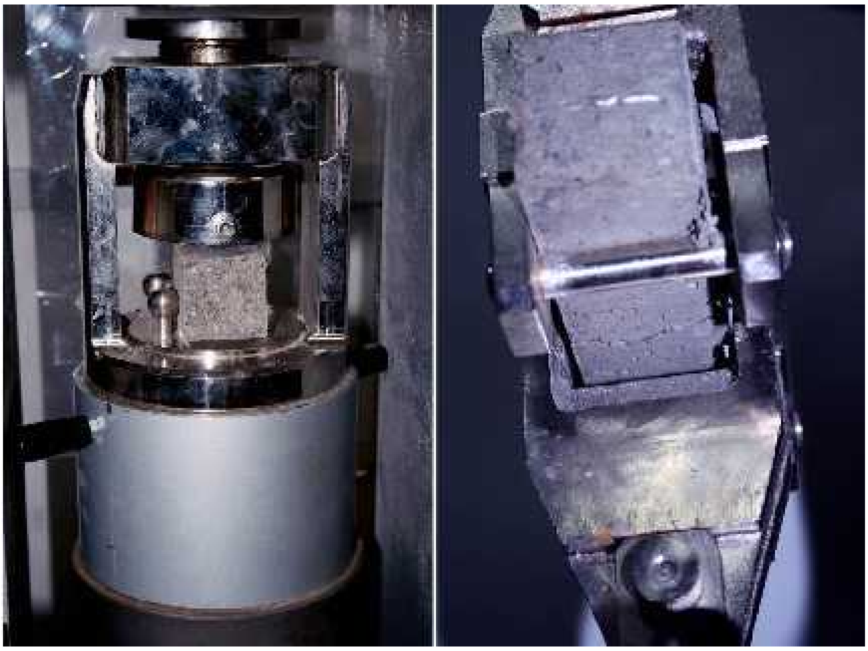

Fig. 3. *Compression (a) and flexural strength test (b).*

Three-point bending test was performed to evaluate the influence of CFs on flexural strength of mortar. The distance between the supporting points was 10 cm and the load was applied in uniform 50 N/s rate. The tests were performed with the Automatic Flexural Tensile Tester L15 from Controls, Italy. Using the sample halves remained after flexure test the compressive strength tests were performed with a 250 kN hydraulic press from Tecnotest, Italy in the UTCN Laboratory. The mentioned tests were performed according to [7].

The adhesion of hardened mortar to the substrate was determined with the 58-C0215/T pull-off tester from Controls, Italy [8]. A ~10 mm mortar layer was applied to previously humidified full bricks which were maintained in a vertical position during the application (Figure 2). The tests were then performed at 28 days.

3. Results and Discussions

The control cementitious mortar (R1) was tested and compared with the carbon fibre reinforced one (R2). Table 4 indicates the average mechanical strength of the FRCC compared to the plain mortar.

From the results presented in Table 4 and Figure 4, it can be observed that an amount of 13.5g of carbon fibres in cementitious mortars (4.5 dm^3) result in good mechanical strengths compared to plain mortar.

Technical characteristics obtained Table 4.

Recipe	**Apparent density** [kg/m^3]	**Compressive strength** [N/mm^2]	**Flexural strength** [N/mm^2]	**Adhesion to the support layer** [N/mm^2]
R1	2401.78	25.21	4.99	0.06
R2	2417.86	25.70	5.91	0.06

The plain mortar and the reinforced as well falls into class 20 (masonry mortars) and class CS IV (plastering mortars) based on compressive strength at 28 days (Tab. 4). In the case of apparent density there is no significant difference between R1 and R2. Both recipes belong to the category of heavy mortars (exceeding the density of 1800 kg/m^3).

The results of the tests and this research also indicate that a small quantity of CF improves the post-cracking behaviour of the composite.

In the case of CFRM, the maximum compressive strength at 28 days increased only 2% compared to the traditional mortar without any additives or chemical agents, while the maximum flexural strength increased 18.5%.

Fig. 4. *Failure modes of the specimens under the compression loading test and the materials (plain and CFRM) meso structure.*

4. Conclusions

In this study, the potential use of short fibres as reinforcement was analysed and investigated by incorporating 6 mm length carbon fibres into cement-based mortars. The principal mechanical properties were investigated such as compression and flexural strength and compared to the plain, unreinforced mortar.

CFRMs have greater flexural strengths than the traditional mixture, while the compression strength does not differ significantly.

It was also found that CFs do not affect the composite workability greatly. The consistency of fresh mortar in the case of two recipes was similar.

The results of the tests and this research indicate that a small quantity of CFs incorporated in the cementitious matrix improve the post-cracking behaviour of the composite.

The brittle behaviour and the deficiency of plain mortar can be improved by using chopped carbon fibres as reinforcement and the following conclusions can be drawn:

- in the case of CFRMs, the maximum compressive strength increased at 28 days by 2% without additives or chemical agents;
- the maximum flexural strength increased at 28 days by 18.5%;
- one of the advantages of using CFs as reinforcement is a better cracking tolerance and the formation of a "bridge" across the cracks during and after failure;
- the crack in the case of unreinforced specimens grew suddenly after appearing, but in the case of CFRMs a slow evolution was observed;
- in terms of adhesion to the support layer the difference is not measurable.

The findings of this research represent the basis of a future study which aims to investigate the behaviour of CFRMs using multi-scale virtual analyses.

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