



# The influence of calcium oxide addition on properties of fiber reinforced cement-based composites

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## ABSTRACT

In this project several fiber reinforced cement-based composites (FRCCs) were studied, in which a CaO-based expansive agent was added in order to help in reducing the cracking induced by drying shrinkage. Two different kinds of fibers were tested: brass-coated hooked steel fibers and flat and flexible amorphous metallic fibers. All the mixtures were characterized for fresh and hardened state, by measuring the consistency of fresh mixtures, compressive and flexural strength, as well as length changes under drying shrinkage test condition for the hardened state. Their microstructures were also investigated by mercury intrusion porosimeter and SEM observations. The effect on mechanical performance of thermal pre-treatment at 80 °C was also evaluated. Results obtained confirmed the effectiveness of CaO addition (even at a low-dosage) on the stability of mixtures under drying shrinkage. It also proved to be effective in terms of flexural strength improvement when used with brass-coated fibers. The reason of this synergy probably lies in the formation of calcium hydroxylzincate (CHZ) crystals at the interface between the fibers and surrounding cement paste. These CHZ crystals, as observed by SEM, are likely able to noticeably improve the quality of the interface of the fiber-matrix by increasing adhesion.

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## 1. Introduction

Cement-based materials (i.e. slurries, mortars, and concretes) are the most widely used construction materials because they generally develop high strength, high toughness, and improved durability. However, in certain environmental conditions drying shrinkage and the related cracking can be responsible for their reduced durability. It has been established that incorporating fibers into cementitious materials can effectively improve their toughness and ability of withstand cracks [1–2].

In order to improve the performance of fiber reinforced cementitious materials, in terms of reducing the crack formation, expansive agents have been studied [3–4]. The addition of expansive agent on plain concrete (without fiber reinforcement) has been shown to be able to somewhat increase the compressive strength, marginally change the flexural strength, and above all produce initial expansion with consequent reduced final shrinkage at longer ages [5–7].

Moreover, an interesting application is that of the so-called Chemical Prestressed Reinforced Concrete (CPRC), which is obtained by adding expansive agent to the mixture, without fiber reinforcement [8–9]. Sahamitmongkol and Kishi [8–9] found a

certain compressive prestress effect due to the external constraint offered by reinforcement bars to the expanding cement matrix, which was able to increase the flexural behavior. However, this reinforcement, which was localized (and not diffused), did not allow to fully utilize the prestress effect because it involved only a small portion of the matrix, which was the thin layer located nearby reinforcement bars. In theory, it would have been more effective for a fiber reinforcement to be uniformly distributed throughout the material undergoing tensile stress when put in bending.

The study of concrete containing both short fiber reinforcement and expansive agent in the cement mixture has been quite limited until now [3–4,10–14]. This is the combination that has been mainly investigated in this project with the aim of reducing autogenous shrinkage more than of improving mechanical performance in bending.

Sun et al. [3] showed that the incorporation of expansive agent with sufficient amount made the interfacial strength between shrinkage resisting components (aggregates and fibers) and cement paste improved, especially in the early hydration period. They found improved pore structure of the concrete, as well as improved shrinkage resistance and improved impermeability of the concrete.

Toutanji [11] showed that the effect of an expansive agent combined with a shrinkage reducing admixture (SRA), in the presence of polypropylene fibers, had led to a slight decrease of

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compressive strength, splitting tensile strength, and elastic modulus.

Park et al. [10] found that another expansive agent (mainly based on calcium sulpho-aluminates) combined with SRA did not show any positive effect on the mechanical performance of an ultra-high performance concrete UHPC, while it was able to reduce autogenous shrinkage by 80%.

Huang et al. [12] studied a cementitious mixture in order to produce a shotcrete that contained both an expansive agent and short steel fibers. They noticed an improvement of the 28-day flexural strength.

Aiguó et al. [4] studied a cementitious mixture containing magnesium oxide as expansive agent and steel fibers. They noticed some improvement of splitting tensile strength (+38%).

Cao et al. [13] produced a lightened high-strength mixture by using both high-modulus steel fibers and expansive agent in which a certain synergic effect of expansive agent and steel fiber was reported in terms of flexural strength.

He et al. [14] found that by adding an expansive agent to cement-based materials reinforced by steel bars and/or steel fibers, it could produce a “self-stressing cement”, in which the expansion after cement hydration was significantly restrained such that the steel bars and/or steel fibers were tensioned, and were able to create compressive pre-stresses in the cross section, usually in the range 3–6 MPa.

## 2. Research significance

The general purpose of this work was to study the influence of a CaO-based expansive agent on the properties of cement-based composites reinforced with two different type of metallic fibers: brass-coated hooked steel fibers (Brass) and flexible amorphous metallic fibers (Flat).

In particular, the first objective was to verify the positive influence of the CaO-based expansive agent on reducing the drying shrinkage of the metallic fiber reinforced cement-based composites.

The second objective was to evaluate the influence of the CaO-based expansive agent on the flexural strength of FRCC with a high-volume of metallic fibers. It is reported in the literature that an improvement of tensile and flexural strengths is found due to a certain synergy between expansive agent and steel fibers [4,12–14]. However, the mechanism through which this likely synergy develops was not investigated. It was presumed that it could be the same as that found in the Chemical Prestressed Reinforced Concrete (CPRC) technology [8–9,14].

The third objective was to evaluate the effectiveness of a 24-h thermal treatment at 80 °C on the values of compressive and flexural strengths.

## 3. Materials and methods

Fibers were separately added to superplasticized cement-based mixtures, at a rate of about 1.9% and 1.4% by volume of the mixture, for 'Brass' and 'Flat' type, respectively. Moreover, special FRCCs were also manufactured by adding a low-dosage of the CaO-based expansive agent (20 kg/m<sup>3</sup>) in order to help in reducing the risk of cracking induced by drying shrinkage and to improve the durability. All the mixtures were prepared with the same w/c ratio of 0.30 and the same sand/cement ratio of 2.3, as well as the same amount of a polycarboxylate-based superplasticizer (3.6% by weight of cement). A control superplasticized mixture with expansive agent (Exp), with the same w/c, the same sand/cement ratio, but without fibers was manufactured and evaluated. Finally, two control superplasticized mixture with either hooked steel

fibers (Brass) or flexible flat metallic fibers (Flat), with the same w/c, the same sand/cement ratio, but without expansive agent were manufactured and evaluated.

All the mixtures were characterized for fresh and hardened state, by measuring fresh consistency, compressive and flexural strength, as well as length changes under drying shrinkage test. Moreover, their microstructures were investigated by means of Mercury Intrusion Porosimeter (MIP) and Scanning Electron Microscope (SEM) observations. The effect on mechanical performance of a 24-h thermal pre-treatment at 80 °C was also evaluated.

### 3.1. Materials

Commercial portland-limestone blended cement type CEM I 52.5 R, according to the European Standards EN-197/1, was used [15]. The Blaine fineness of cement was 0.48 m<sup>2</sup>/g and its relative specific gravity was 3.15.

Well-graded very fine natural sand was used with particle size up to 1.0 mm.

The steel fibers used in this project were:

- Hooked brass-coated steel fibers (30-mm long, 0.5 mm diameter), aspect ratio of 60, relative specific gravity of 7.87; and,
- Flat and flexible metallic fibers (30-mm long, 1.6-mm wide, 0.029-mm thick), aspect ratio of 120, relative specific gravity of 7.22.

A polycarboxylate-based superplasticizers was used (at 3.6% by weight of cement). It was constituted by a carboxylic acrylic ester polymer in the form of  $26.8 \pm 1.3\%$  aqueous solution: this is a new formulation promising to be effective in reducing water dosage.

A dead-burnt calcium oxide (CaO) was used at a low-dosage of 20 kg/m<sup>3</sup> (usually 30–50 kg/m<sup>3</sup> is the recommended dosage in order to use CaO as expansive agent [12–13,16–20]).

Calcium carbonate (CaCO<sub>3</sub>) was used at a dosage of 110 kg/m<sup>3</sup> in order to obtain a volume of very fine particles (grain size under 0.150 mm) of about 200 litre per m<sup>3</sup> of mixture (including 500 kg of cement). This mineral addition was necessary (in addition to a high dosage of superplasticizer) in order to obtain enough fluidity without segregation. In fact, FRCCs are so rich of metallic fibers (either 1.4% or 1.9% depending on the type of fiber) that flow segregation could occur if rheology is not properly studied and sufficient cohesion is not assured [20–22]. The dosage of calcium carbonate was raised up to 130 kg/m<sup>3</sup> in the mixtures where calcium oxide was not added (in order to replace it for comparison purpose).

### 3.2. FRCC mixture proportions

Five different FRCC mixtures were prepared by using the same water to cement ratio of 0.30, the same dosage of acrylic-based superplasticizer equal to 3.6% by weight of cement in order that adequate workability could be achieved. Cement and fine sand were used at the same dosages of 500 kg/m<sup>3</sup> and 1130 kg/m<sup>3</sup>, respectively. In two mixtures, 100 kg/m<sup>3</sup> of type 'Flat' fibers were added, with and without calcium oxide. In other two mixtures, 150 kg/m<sup>3</sup> of type 'Brass' fibers were added, with and without calcium oxide. Different dosage were chosen in the two cases was due to the different geometry of the fiber used (and also due to slightly different specific gravity), and due to the consequent effect of fiber addition on FRCC rheological behavior. In this manner the same fresh workability values were obtained. Workability of FRCCs at the fresh state was monitored by means of the flow table according to the procedure described in EN 1015-3 [23]. Results obtained in terms of consistency of fresh FRCCs were equal to 180 mm, segregation was not noticed. Higher values of fresh workability (250 mm) were detected for the reference mixture

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