Early-Age Behaviour of Fiber Reinforced High Performance Concretes

New Gen Materials for Structural Concrete Building

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***Abstract*— The aim of this experimental activity was to study the early-age behavior of several Fiber-Reinforced Concretes (FRCs) containing expansive agent. The investigation concerned the evaluation of the influence of different amounts of fibers (dosages of 2.0%, 1.75% and 1.5% by volume of FRCC) on the mechanical performance of FRCs. In particular, hooked brass-coated fibers were used and dead-burnt calcium oxide based expansive agent was employed at a dosage of 40 kg/m^3. The attention was focused on the strength development at early ages. Mechanical tests were carried out at 0.25 (i.e. 6 hours, that is time of demolding), 1, 2, 7 up to 28 days of curing. The properties of FRCs were characterized at the fresh state, by measuring flow ability and consistency as well as at hardened state by measuring compressive and flexural strength up to 28 days. Flexural strength was measured on prismatic specimens according to the procedure described in EN 12390-5. The different dosage of fibers did not influence the values of compressive strength, while there is a significant difference in terms of 28-day flexural strength between the several mixtures depending on the different amount of fibers. In all cases at least 20 MPa of 28-day peak flexural strength were achieved.**

***Index Terms*— Advanced Materials, Building, Early age, Fiber Reinforced Concrete, High Performance Concrete, UHPC**

I. INTRODUCTION

Cement-based materials (i.e. mortars and concretes) are the most used construction materials because they offer significantly higher economic efficiency compared to other construction materials, as well as remarkable mechanical performances and durability. However, cement-based materials also have some weak points, such as low bending and tensile strength compared to their weight, and brittleness. Recently, many researchers are involved in the development of innovative FRCs, and in particular UHPCs, in order to overcome such problems.

The use of expansive agent on concrete (in absence of fiber reinforcement) proved to be able to increase a little the value of compressive strength, to maintain the same level of flexural strength, and among other things to produce a significant initial expansion by reducing in turn the drying shrinkage value at long ages [1-3].

Moreover, a new formulation was studied [4-5] involving the addition of expansive agent to the mix of a kind of concrete that is not fiber reinforced but containing steel rebars: Chemical Prestressed Reinforced Concrete [4-5]. Sahamitmongkol & Kishi found a certain compressive prestress effect caused by the external constraint offered by the steel bar reinforcement to the expanding cement matrix. This constraint is able to generate internal stress and in such a way to increase the flexural strength of the cement-based material. However, steel bar is a localized reinforcement, not uniformly and homogeneously distributed in the cement matrix. In such a way the prestress effect is not fully exploited because only a thin portion of material is involved, that is the thin layer of concrete surrounding the reinforcement bars. In theory, a fibrous reinforcement uniformly distributed would be much more effective in terms of tensile stress realize when the concrete is put in bending.

Nevertheless, in the scientific literature there are few studies of concrete prepared by using together short fiber reinforcement and expansive agent [6-11]. The combination among fibers and expansive agent has been mainly investigated till now for reducing autogenous shrinkage and not for improving bending strength of concrete.

Sun et al. [6] showed how the addition of expansive agent at suitable dosage increased the interfacial strength between those components (aggregate particles and fibers) able to counteract drying shrinkage, and the cement paste, especially at early age. This joined addition was able to refine the pore structure of concrete, as well as to reduce shrinkage and permeability of concrete.

Toutanji [7] showed that the combined effect of expansive agent and shrinkage reducing admixtures in the presence of polypropylene fiber reinforcement led to a slight lower compressive strength, splitting tensile strength and elastic modulus.

Huang et al. [8] studied a cement-based mixture suitable to produce shotcrete, in which both expansive agent and short steel fibers were added. They noticed a ceetain improvement of 28-day flexural strength but never higher than 7 MPa.

Aiguo et al. [9] studied a concrete mixture containing MgO-based expansive agent and steel fibers. They noticed a certain improvement in terms of 28-day splitting tensile strength.

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Cao et al. [10] studied a lightweight high-strength mixture by using steel fibers and expansive agent. They found a slight synergic effect between expansive agent and steel fibers in terms of increased flexural strength.

He et al. [11] studied the addition of expansive agent to cement-based materials reinforced by steel bars and/or steel fibers. In that way they obtained the so-called 'self-stressing cement', in which the matrix expansion due to cement hydration is restrained and consequently the steel bars/steel fibers are put in tension. In that way they were able to create a compressive pre-stresses of about 3-6 MPa.

Finally, Corinaldesi et al. [12-13] tried to add CaO-based expansive agent to FRCs and they proved that flexural strength can be enhanced, especially if used with brass- and zinc-coated hooked fibers [14] and ribbon-shaped amorphous metallic fibers [15-18].

II. RESEARCH SIGNIFICANCE

This work was aimed at evaluating the influence of different amounts of steel fibers on the mechanical properties of FRCs prepared with CaO-based expansive agent. Mixtures were prepared by varying the dosage of hooked brass-coated fibers: ranging from 1.5% to 1.75% up to 2% by volume of concrete, respectively.

In particular, the attention was focussed on the mechanical performance at early ages: 6 hours (time of demoulding), 1, 2, 7 and 28 days of wet curing. The experimental data collected after only 6 hours are important for likely application in precast concrete plant.

III. MATERIALS AND METHODS

Commercial portland cement, type CEM I 52.5 R, according to EN-197/1 was used. The Blaine fineness of this cement was 0.48 m^2/g and its density was 3150 kg/m^3.

As inert fine quartz sand was used, with particle size between 0.2 and 4.0 mm. Moreover, silica fume powder (SF) was added at a dosage of 120 kg/m^3 with grain size smaller than 1 μm, obtained as industrial by-product of the silicon processing. Silica fume used had a BET value of about 18 m^2/g, and a density of 2200 kg/m^3.

A calcium carbonate powder was used as filler at a dosage of 55 kg/m^3 in order to reach an overall volume of very fine particles (under 0.150 mm) of about 250 liters per m^3 (including calcium carbonate, silica fume and cement). In that way, thanks to a high dosage of superplasticizer high fluidity without segregation can be achieved.

Hooked brass-coated steel (Br) fibers (30-mm long, 0.50 mm diameter) were used, with aspect ratio of 60, relative density of 7.82, and elastic modulus of 210 GPa.

Dead-burnt calcium oxide (CaO) was used always at the same dosage of 40 kg/m^3: in agreement with the recommended values for CaO-based expansive agents between 30 and 50 kg/m^3 [1-2, 19-20].

The mixture were prepared with a water to cement ratio of 0.34. Their mixture proportions are shown in Table 1.

All the mixtures were prepared with the same w/c ratio of 0.34 and inert/cement ratio of 2.15, as well as the same dosage (2.5% by weight of the cement) of a 27% aqueous solution of carboxylic acrylic ester polymer based superplasticizer.

Workability at the fresh state was evaluated by means of the flow table according to the procedure indicated in EN 1015-3 (Determination of consistence of fresh mortar by flow table, 1999). All fresh mortars showed a consistency value corresponding to S5 class (slump higher than 210 mm). All the prepared specimens were demoulded after 6 hours (just at the ending of the setting time, to avoid expansion of cement mixture within steel forms). After two days of wet curing they were exposed up to 28 days to a dry environment at a temperature kept at 20°C.

TABLE 1. MIXTURE PROPORTIONS (KG/M3)

Ingredients	Mixtures		
	Br-2%	*Br-1.75%*	*Br-1.5%*
Cement	590	595	595
Water	203	205	205
Sand (0-4 mm)	1275	1280	1285
Superplasticizer	15	15	15
Silica Fume	120	120	120
Brass fibers	156	137	118
Limestone filler	55	55	55
Expansive Agent	40	40	40

For each FRC were prepared two prismatic specimens (100 x 100 x 400 mm) and three cubic specimens (100 x 100 x 100 mm) for each curing time. These specimens were used to evaluate FRC mechanical behavior. They were cast in steel forms (vibrated for 15 seconds after casting).

Flexural strength of FRCs was evaluated after 6 hr, 1, 2 and 7 days of curing, according to EN 12390-5 (Testing hardened concrete: flexural strength of test specimens, 2002) on two prismatic specimens for each mixture and curing time.

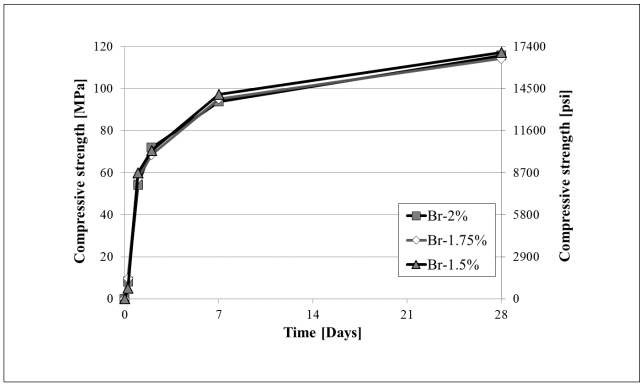


Fig. 1 - Compressive strength vs. curing time.

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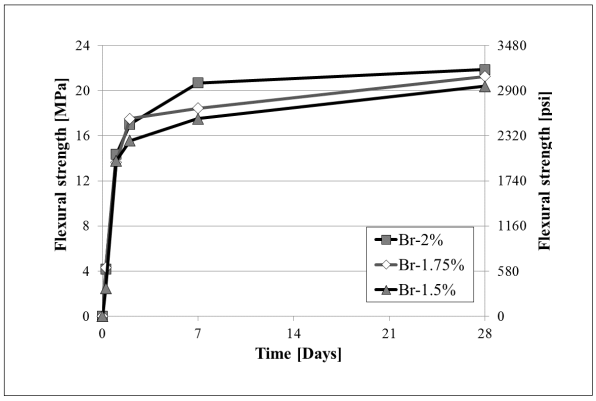


Fig. 2 - Flexural strength vs. curing time.

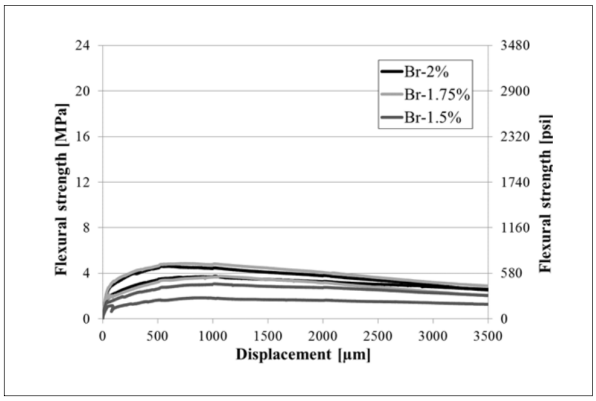


Fig. 3 - 6-hour flexural strength vs. displacement

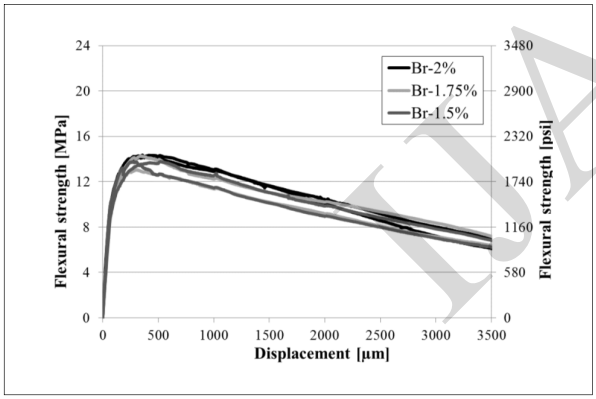


Fig. 4 - 1-day flexural strength vs. displacement

IV. RESULTS AND DISCUSSIONS

Compressive strength of FRCs was evaluated on 100-mm side cubic specimens after 6 hr, 1, 2, 7 and 28 days of wet curing. On the basis of the results reported in Fig. 1, it can be observed that a 1-day compressive strength value of at least 50 MPa was reached in all cases.

The results obtained after one week of wet curing are in the range 90 to 100 MPa, while in all cases after 28 days a value of about 120 MPa was reached, independently on the amount of fibers, which does not seem to influence the compressive strength value.

On the basis of the results reported in Fig. 2, it can be noticed that at very early age the different dosages of fibers does not affected the flexural strength. However, a value of 1-day flexural\strength of at least 13 MPa was reached in all cases.

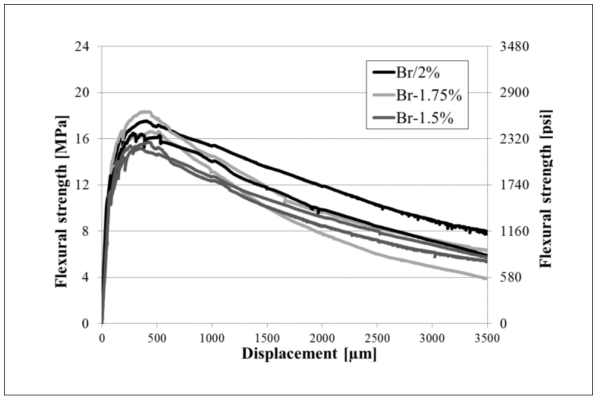


Fig. 5 - 2-day flexural strength vs. displacement

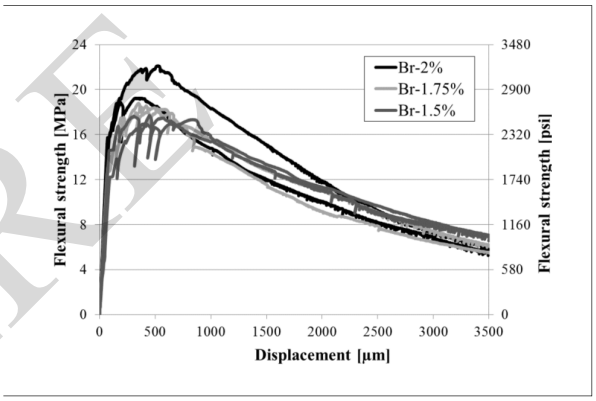


Fig. 6 - 7-day flexural strength vs. displacement

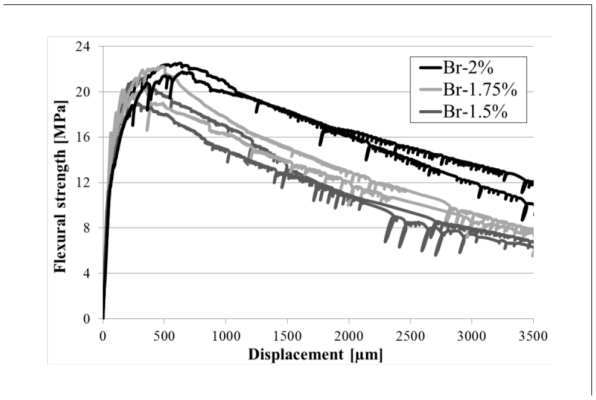


Fig. 7 - 28-day flexural strength vs. displacement

After 28 days of wet curing a minimum value of 20 MPa was obtained even when the minimum dosage of fibers, equal to 1.5% by volume, was added.

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On the other hand, the highest dosage of fibers (equal to 2% by volume) seems to have positively influenced the post-cracking behavior, also in terms of residual stresses (see Fig. 7).

V. CONCLUSIONS

The following general conclusions can be drawn from this study:

– The dosages of fibers did not influence the compressive strength; in all cases a 1-day compressive strength value of at least 50 MPa was achieved, while the 28-day compressive strength was in the range of 115-120 MPa, independently of the amount of fibers.

– In terms of flexural strength at very early ages (up to 24 hours) no difference was detected, while after 7 days of curing a difference of about 3 MPa between the mixtures with minimum (1.5%) and maximum dosage (2%) of fibers was observed. However, at least 13 MPa of 1-day flexural strength was reached in all cases, as well as a minimum 28-day flexural strength of 20 MPa.

– Residual flexural strength at a displacement of 3.5 mm seems to be independent of the amount of fibers up to 7 days of curing, then the higher dosage of 2% by volume seems to promote a better post-cracking behaviour.

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