EVALUATION OF A HYBRID SYSTEM OF ADMIXTURE AND FIBRE FOR DEVELOPMENT OF SHRINKAGE RESISTANT CEMENT-BASED MATERIAL

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Abstract

Shrinkage is a crucial feature in concrete and mortar members as it results in volume change that can lead to cracking and consequently to serviceability problems.

Different additives and methods have been proposed to compensate for this problem mainly through the use of shrinkage reducing admixtures, fibres and expansive agents. In this paper, several combination systems of polyethylene micro-fibre along with an inorganic expansive agent have been studied for their influence on drying shrinkage. This special type of fibre, reported to act as shrinkage reducer, had been used in different concentrations in mortars and had been shown to have advantages and disadvantages. On the other hand, expansive agent, ammonium polyphosphate, had been shown to reduce drying shrinkage and modify most of mechanical properties.

Free shrinkage strains as well as some physical properties of new mixes which contain polyphosphate and polyethylene micro-fibre are reported in this study. Several combinations were used and have been shown to have promising results in drying shrinkage, physical and mechanical properties.

1. INTRODUCTION

The drying of concrete and mortar in ambient conditions results in volume changes. Shrinkage in restrained cement-based materials leads to shrinkage cracking which has adverse effects on the serviceability and durability of the structural members. Despite considerable amount of research which has been carried out to solve this problem, more research needs to be conducted to fully understand the best compensating mechanism as all the current shrinkage reducing materials and methods have their own side effects [1].

Immediately after mortar and concrete specimens have been exposed to drying conditions, free water is lost [2]. The loss of free water from large cavities present in paste microstructure may not result in shrinkage; however the loss of adsorbed water and water held in small capillary pores is likely to result in a reduction in the disjoining pressure [3], which is known to be an important mechanism of drying shrinkage where the relative humidity is above 50% [4, 5].

A number of strategies have been developed in order to either reduce or compensate for mainly drying shrinkage, which is the major contributor in total shrinkage of normal strength concrete [1, 3]. Shrinkage reducing admixtures SRA are new materials which directly affect surface tension of capillary pore water resulting in a decrease of shrinkage made by surface tension mechanism [1]. SRAs have also been reported to retard the hydration process of Portland cement [6].

Reduction in drying shrinkage can also be achieved by using expansion mechanism, which compensates for shrinkage through the introduction of expanding phases in the pore structure [7]. Reacting with water, calcium sulfo-aluminate (CSA) admixture forms ettringite and expands, while the expansion in the lime-based system is due to the crystal growth and the pressure that results when CaO particles convert to $Ca(OH)_2$ [8].

Another approach to prevent shrinkage effects is to provide reinforcement in concrete by using fibres which are expected to be discontinuous, and randomly distributed throughout the cement paste matrix, and in consequence they act well in crack controlling [9].

In addition, these strategies can be applied in combination as hybrid additive systems producing a synergistic effect. Most of hybrid systems have been tested using different types of fibres [10-12]. There are also some hybrid systems that include expansive agents and fibres [13]. In this research, a set of hybrid systems, containing a new inorganic expansive agent and a micro-fibre type of polyethylene, minifibre, is studied. This type of inorganic expansive agent is used in order to improve mechanical properties mixes containing polyethylene minifibres.

2. SIGNIFICANCE

Fibres are commonly known for their immediate effects in shrinkage cracking resistance, rather than shrinkage reduction. Fibres do not greatly modify the cracking time, but do reduce the crack width [14]. As such, fibres are usually used in combination systems in order to reduce shrinkage effects.

There is limited number of combination systems used in experimental shrinkage studies [11, 13, 15]. Hybrid combinations used in this study include a new type of polyethylene minifibre in combination with ammonium polyphosphate which is believed to act as an expansive agent. The minifibre is a hydrophobic monofilament polyethylene micro-fibre of 100 μm in length, 5 μm diameter and surface area of 12 m^2/gr. Minifibres have been shown to reduce the amount of moisture loss in samples and this phenomenon may possible be due to blockage of capillary pores inside cement paste matrix and repelling water while they are dispersed in the mix [16].

The new expansive agent mentioned is an inorganic ammonium polyphosphate with ultra high molecular weight [17]. Comparing with current SRAs, low concentration of ammonium polyphosphate is needed to reduce drying shrinkage of the mix. The polyphosphate is expected to react with calcium hydroxide, derived from the cement hydration, resulting in calcium polyphosphate and volatile amine derivative. Calcium polyphosphate is a binder formed inside cement-based material matrix which enhances the physical characteristics of concrete. There are several classes of amine compounds which have been used in concrete industry as corrosion inhibitors [18] and admixtures [19].

Recent work by the authors [16] has shown that this new type of micro-fibre has advantages and disadvantages in regards to engineering properties of cement-based materials. In spite of drying shrinkage reduction, Micro-fibres were shown to decrease compressive strength of mortars since the hydrophobic polyethylene minifibre stores water and result in less moisture loss [16]. In contrast, the polyphosphate agent concentration improves the compressive properties [17]. However, polyphosphate expansive agent containing mortars were reported to have more mass loss than control mortar [17]. This paper reports the results of a study of the combination of polyethylene minifibre and ammonium polyphosphate admixture, used in combination in the mix. Since mortar samples are more vulnerable to dry shrinkage than concrete samples with the same size and shape, they have been used in this research investigation.

3. EXPERIMENTAL METHODS

Australian standards (AS) have been followed for these experiments. The used prismatic moulds for shrinkage test specimens were 40 mm × 40 mm × 145 mm in size.

For the first 20-24 hours after mixing, all specimens were stored in a moist environment where the relative humidity was more than 95%. After demoulding, the shrinkage specimens were initially measured for their length and then stored inside the humidity-controlled cabinet at a temperature of 23 ±1°C and a relative humidity of 50±5%. The length measurements were taken for each specimen at the age of 7, 14, 21, and 28 days after mixing [20].

3.1 Material, mortar mix proportions

Cement mortars were prepared using Goliath General Purpose Cement supplied by Cement Australia and Raymond Terrace single washed sand supplied by Rocla Quarry Products Pty Ltd. Glenium, a high-range water reducing admixture supplied by BASF, was used as superplasticiser. Superplasticiser was used for modification of the mix design proposed in AS 2350.12 [20], in order to maintain constant workability of the mortars. For comparing purposes, all mixes consisted of same concentration of superplasticiser.

All the tests were carried out at 23±1 °C. In order to obtain comparable results for the evaluation of the new additive, 4 different mixes, including a control mix, were prepared on the same day and under the same environmental condition. Mortar mix designs, presented in Table 1 were taken from standardized proportions listed under AS 2350.12 [21] and modified based on flow properties. Superplasticiser additions were made directly to water before commencement of mixing.

Table 1: Mix design proportions of mortar specimens

Raw material / Mixes	Cement(g)	Sand(g)	Water(g)	Superplasticiser(mL)	Fibre(g)	Expansive agent(g)
Co	450	1350	224.35	1	0	0
Fi0.1+Ex0.5	450	1350	224.35	1	0.45	2.25
Fi0.5+Ex0.5	450	1350	224.35	1	2.25	2.25
Fi0.5+Ex1.0	450	1350	224.35	1	2.25	4.5
Fi1.0+Ex0.5	450	1350	224.35	1	4.5	2.25

The shrinkage reducing additives including expansive agent and minifiber were first introduced to cement and well vibrated in order to have a consistent mixture of cement and additives.

As shown in Table 1, the term “Co” stands for the control mix without any fibre or expansive agent. Terms Fi0.1+Ex0.5 stand for mixes with polyethylene fibres concentration of 0. 1% and expansive agent dosage of 0.5% of cement weight, respectively. Regarding 28-day compressive strength, expansive agent concentration of 0.5% was the optimum one [17]. Mixing and casting of mixes with more than 1.0% concentration of minifiber was also reported to be difficult, since the produced mix was not workable enough for mixing and casting [16].

3.2 Shrinkage measurement

Immediately after demoulding, all specimens were subject to initial length measurement to the nearest 0.001 mm, using length comparator. Subsequent measurements were also taken at the ages of 7, 14, 21 and 28 days after mixing. The drying shrinkage for 7, 14, 21 and 28 days after mixing was calculated [20].

3.3 Physical properties

Physical properties of mixes were also studied. The list includes flow, mass changes of specimens during 28-day ambient storage and 28-day compressive strength, of each mix [22].

4 RESULTS AND DISCUSSION

4.1 Fresh properties

Flow cone samples of Fi1.0+Ex0.5 were cracked and broken during flow test since it was dry and not workable enough. Figure 1, shows the flow of other mortars based on measurements carried out in accordance with ASTM standards [23]. A reduction in workability was observed with increasing additions of minifibers. Figure 1 also suggests that 0.5% addition of polyphosphate admixture modified the flow of Fi0.1, comparing to previous study [16].

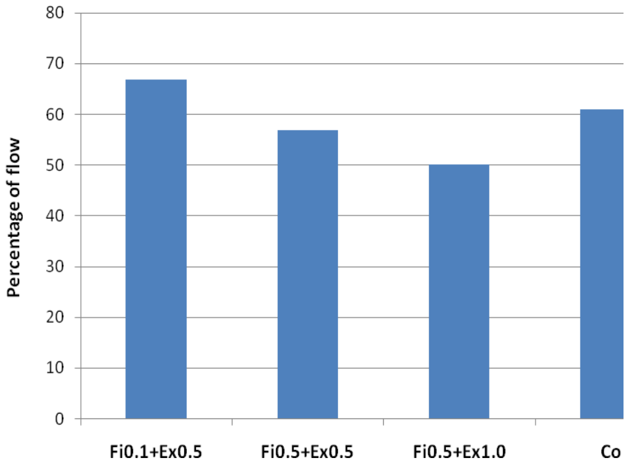

Figure 1: Flow of mixes

4.2 Hardened properties

4.2.1 Drying shrinkage

Drying shrinkage behaviour of different samples after 28 days storage in humidity and temperature-controlled environment is shown in Figures 2. Figure 3 also illustrates the free shrinkage strain of mixes during 28 days of mixing. From these figures, drying shrinkage is found to reduce in hybrid mixes by 17-23% which is not further more than the last studies by the authors [16, 17].

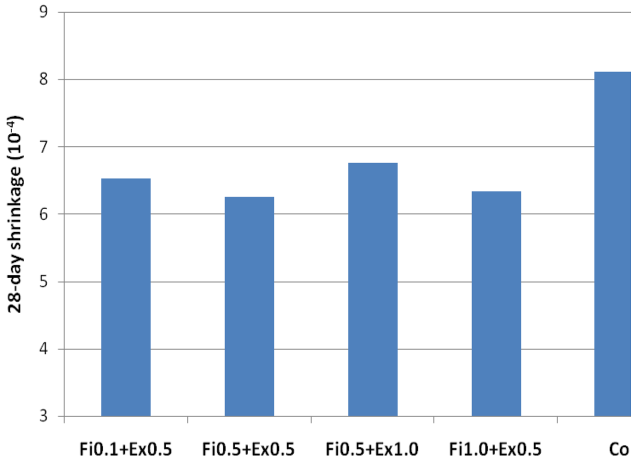

Figure 2: 28-day shrinkage of mixes

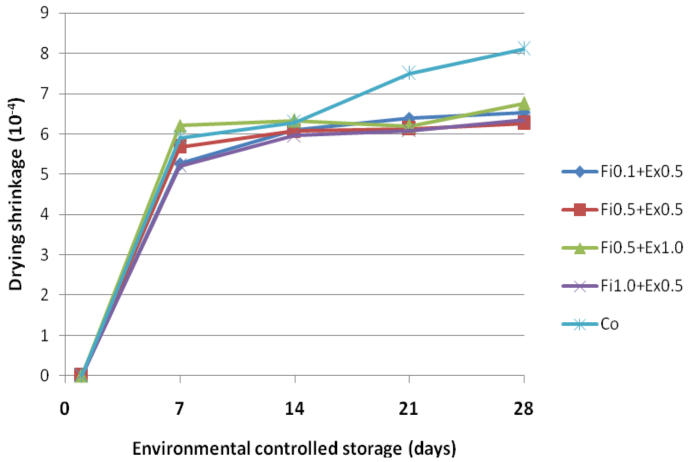

Figure 3: Drying shrinkage vs. time

4.2.2 Compressive strength

Specimens with polyethylene minifiber had been reported to have lower compressive strength when compared to the Co mix [16] and these results were in agreement with results of Zheng and Feldman [24]. Strength reduction of polyethylene fibre may be due to its hydrophobicity which can affect cement hydration rate in areas around micro-fibre. It can also be due to the fact that hydrophobic fibres do not bond well with the cement matrix resulting in less compressive strength.

Figure 4 depicts the 28-day compressive strength of the hybrid systems. Dissimilar to previous study [16], compressive strength is not reduced and it is even improved due to the presence of polyphosphate admixture. Inclusion of the polyphosphate expansive agent with the minifibers in this study was observed to improve the compressive strength.

Compressive strength of hybrid mortars incorporating low addition amounts of minifibers, such as 0.1% was higher than the compressive strength of control mix due to the production of calcium polyphosphate which acts as a binder [17]. But with increasing minifiber additions with the same amount of polyphosphate, the compressive strength was found to decrease marginally in Figure 4.

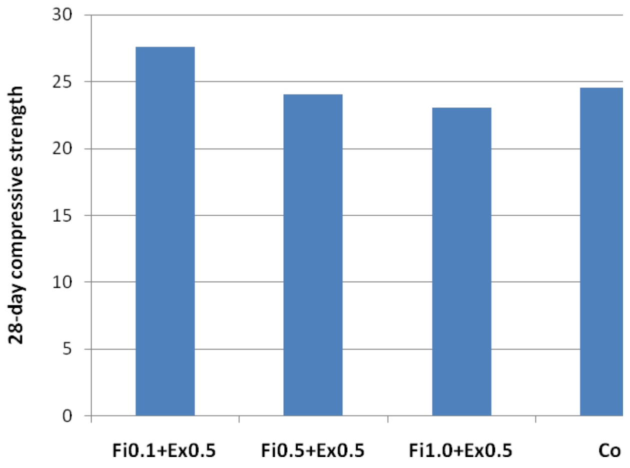

Figure 4: 28-day compressive strength

4.2.3 Mass loss

Change in mass of samples, is another important criterion in this research. Reduction in mass begins immediately after demoulding. This criterion can aid the understanding of the mechanism of shrinkage compensating additives through monitoring the drying behaviour of mortar samples during storage period, based on collected time-dependent data. Figure 5 demonstrates the change in mass which is calculated as a percentage of the initial mass reading.

Polyethylene minifibres had been reported to decrease moisture loss, since it is believed to block the pore structures of the cement paste [16]. Figure 5 supports this idea. It also shows that using polyphosphate agent increases weight loss of mixes in agreement with previous studies [17]. Mass loss of is also observed to increase with increase addition rate of the micro-fibre above the optimum addition rate of 0.1%. In general, all the hybrid mixes have shown to increase weight loss corresponding with increased moisture loss.

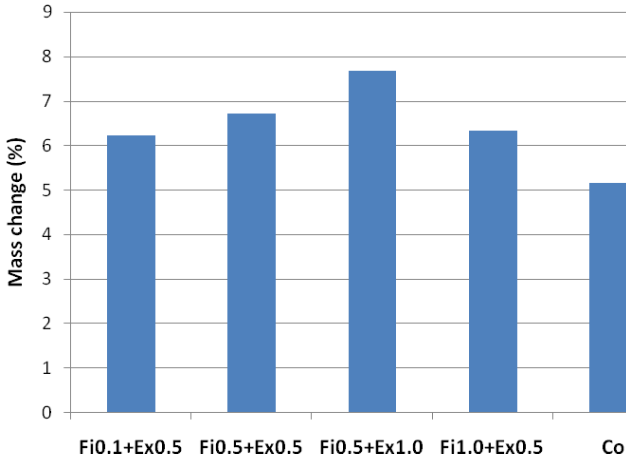

Figure 5: Mixes mass loss after 28-day

5 CONCLUSION

Two mixes, Fi0.1+Ex0.5 and Fi0.5+Ex0.5, seem to be the optimum mixes regarding drying shrinkage and mechanical properties. In addition, adding polyphosphate expansive agent has been illustrated not only to decrease drying shrinkage of mortar mixes, but even modify the flow and compressive strength of polyethylene micro-fibre-reinforced mixes. However, in terms of flow, the mix with 1.0% of minifibre could not be improved with 0.5% of expansive agent. In conclusion, polyphosphate admixture had the dominant effects on mortar mixes characteristics in comparing with the effects of polyethylene micro-fibre.

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