Impact, Compressive and Flow Properties of Fibre Reinforced Cementitious Composites

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ABSTRACT

An experimental study on the effect of fibres on impact and compressive strengths as well as flowability is reported. The expansion during hydration of cement in water and the drying shrinkage of fibre reinforced cementitious composites are also investigated. Cementitious samples are prepared containing varying amounts of E-glass and two types of polyacrylonitrile fibres (Dolanit 10 & 11). Results show that while E-glass and Dolanit 11 could somewhat increase the compressive strength of cementitious samples, Dolanit 10 shows an opposite effect when incorporated into cement. All fibres, depending on their nature and volume fractions, improve the impact strength of the composite considerably. Furthermore, inclusion of fibres reduces the drying shrinkage of cementitious samples, although the flowability of mixtures decreases with increasing of volume fraction of fibres.

Key Words

cementitious composite, impact strength, compressive strength, flowability, drying shrinkage.

INTRODUCTION

Plain concrete or cement is brittle and strain-rate sensitive. This limits the use of concrete where the possibility of impact loading exists. Impact loading is characterized by a large amount of external energy suddenly being imparted to a structure or to a structural element. Because of the complex stress wave patterns associated with impact loading, and the complex energy transfer and energy dissipation mechanisms, the fracture process in cement or concrete subjected to impact is not well understood [1]. To improve the properties of cement or concrete under impact loading, the addition of fibres has been suggested. The post-elastic ductility (or toughness) of fibre reinforced cementitious composites under static loading [2,3] predicts greatly enhanced impact resistance of these composites over that of plain concrete. On the other hand, concrete is an excellent and very useful inexpensive structural material which has a high compressive strength. Although addition of fibres is expected to improve the impact strength of cement, the trend of compressive strength changes with the amount of fibre is not well understood and should be tested for each kind of fibre.

Few systematic studies have been performed
to determine the flow (rheological) properties of fibre reinforced cement and concrete. It is known that fibres affect flow or compactibility of cementitious mixtures [4].

Cement or concrete expands when it is maintained under water and shrinks when subjected to a dry environment [5]. If cement or concrete is constrained from shrinkage, compressive stresses then develop and concrete may crack [6]. It is clear that cement cracks more severely than concrete since it has no filler to reduce the amount of shrinkage. One of the methods to reduce shrinkage cracking is reinforcing cement with short, randomly distributed fibres.

In this work, E-glass fibres and two types of synthetic fibres, i.e., polyacrylonitrile fibres (with trade names Dolanit 10&11 from Hoechst) due to their compatibility with cement were chosen to study their effect on impact strength, compressive strength, flowability of cementitious mixtures and expansion and drying shrinkage of cementitious composites.

**EXPERIMENTAL**

A Portland cement with a specific surface area of about 2500 cm²/g was used in making the specimens. The chemical compositions and physical properties of the Portland cement have been previously reported [2].

Two types of Hoechst PAN fibres of different diameters (Dolanit 10&11) were used. The E-glass and Dolanit 10 and 11 were in the form of chopped rovings, 6mm long and 18 µm, 18 µm and 104 µm in diameters, respectively.

The E-glass and Dolanit 10 were used in volume fractions of 1%, 2% and 3% and Dolanit 11 was used in volume fractions of 1%, 3%, 5% and 6%. Mixing was carried out conventionally in an electrically driven mechanical mixer of the epicyclic type which imparted both a rotary and a revolving motion to the mixer paddle. The cement matrix was mixed with fibres and water with 0.3 water to cement weight ratio. After cement was added to the water and mixed for two periods of 60 seconds with a 30-second rest interval, the fibres were sprinkled randomly into the cement matrix. Mixing was completed in two more 90-second time periods with a 30-second rest in between.

All specimens were cast in steel moulds. Control specimens (cement with no fibres) were prepared to study the effect of fibre inclusion. In order to attain better compaction, the compression and length change test samples (expansion / drying shrinkage) were made in two equal layers, each layer being externally vibrated for approximately 60 seconds. The compression, impact and length change samples had 50x50x50mm, 25.4x25.4x62.5mm and 25.4x25.4x285 mm dimensions, respectively. The test specimens were demoulded after 24 hours at room temperature. Compression samples were tested after further cure in a water bath of 20±2 °C for 2, 6 and 27 days, while impact samples were tested after only 27 days immersion. For measuring expansion of samples, first the comparator dial with the test specimen and then the comparator dial with the reference bar in the length comparator were read. Length change of all different samples after the initial comparator reading was calculated as follow:

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L = \frac{L_x - L_i}{G}
\]

where:

- **L** = length change of specimen at any age (mm/mm)
- **Lx** = difference between the comparator reading of the specimen and the reference bar at any age (mm)
- **Li** = initial difference between the comparator reading of the specimen and the reference bar (mm)
- **G** = the gauge length (250 mm)

Length change measurements of samples were made after 6, 13 and 27 days immersion in water after demoulding.

After measuring the expansion, samples were removed from the water and maintained at a temperature of 20±2°C and a relative humidity of 50±4%. Change length due to drying shrinkage of...
specimens was measured after 1, 7, 14 and 28 days conditioning in dry environment in the same way as mentioned for expansion measurements.

At least nine compression specimens and three impact and change length samples for different volume fraction of fibres were tested. All the compression tests reported here were carried out at 1.5 kN/sec constant load rate using a Tinius Olsen Testing Machine. The impact tests were carried out using a Zwick Impact Pendulum Machine and the change length measurements were carried out using a Rombold length comparator. Flow behaviour of fibre reinforced cementitious mixtures was studied using Tonitechnik flow table. After preparation of mixtures, the conical mould, which had the ASTM 230 specifications was placed at the centre of the flow table and filled with two equal layers of mixture. Each layer was tamped 20 times with the tamper. Then the mould was lifted away from the mixture in one minute after completing the mixing operation. Immediately, the table dropped from a height of 12.7 mm for 10 times in 6 seconds. The flow, as the resulting increase in average diameter of the mixture mass, was measured for at least four diameters at approximately equispaced intervals and expressed as a percentage of the original diameter.

RESULTS AND DISCUSSION

The variations of compressive strength with volume fractions of different fibres in cementitious composites after 28 days curing of cement are depicted in Figure 1. Impact strength of fibre reinforced cement after 28 days curing, as a function of fibre volume fraction is shown in Figure 2. Moreover, the flow behaviour of fresh mixture versus fibre volume fraction is depicted in Figure 3. The effect of fibres of different volume fractions on expansion and drying shrinkage of cementitious composites after 28 days retained in a water bath and dry air, respectively, is shown in Figures 4 and 5.

![Figure 1. Variation of compressive strength with volume fraction of fibres for cementitious composites after 28 days curing.](image-url)
Fig. 2. Variation of impact strength with volume fraction of fibres for cementitious composites after 28 days curing.

Fig. 3. Rheological behaviour of fresh mixtures versus fibre volume fraction.
For a specified volume fraction the observed increase of the compressive strength of fibre reinforced cementitious composites (FRC) with curing time is due to hydration of cement for all kinds of fibres studied. As it is shown in Figure 1, Dolanit 11 and E-glass increased the compressive strength of FRC and maximum compressive strengths were obtained for 3% and 1% volume fractions, respectively, and by further increasing the volume fractions of these fibres the strengthening effect of fibre addition was reversed so that the compressive strength approached that of unreinforced cement. But, Dolanit 10 decreased the compressive strength of cement and by increasing its volume fraction the reduction in compressive strength was more considerable. These results, are qualitatively in agreement with observations of Young [4], however the trend of variation of compressive strength with type and volume fraction of fibre is not well understood. As depicted in Figure 2, the amount of impact strength for FRC is more than cement with no fibre and it significantly increases with inclusion of a higher amount of fibre. For every volume fraction, the amount of impact strength measured for Dolanit 11 reinforced composite was found to be more than that measured for composites reinforced with other types of fibres. This is due to the pulling out mechanism of Dolanit 11 that absorbs much more energy than the mechanism of fibre fracture [3]. In fact, the amount of energy absorption is related to the type of fibre failure. SEM studies showed that dominant failure mechanism for Dolanit 10 and E-glass is fibre fracture [3].

The rheological studies performed indicate the degree of consolidation of a mixture is influenced by several factors, the most important of which are probably: -water to cement ratio, -size distribution and amount of aggregate (for mortar and concrete), -type and amount of fibre, -length and aspect ratio of fibre, and -the method of
mixing and consolidation [4]. As depicted in Figure 3, addition of any kind of fibre decreases the workability of the cement mixture. For the same volume fraction, Dolanit 10 reduces the workability more than Dolanit 11. This may be explained by the fact that Dolanit 11 has a higher diameter than Dolanit 10 and therefore, is rather more difficult to interlock in fibre reinforced cementitious composites [7] compared with Dolanit 10. The workability of E-glass is between the two PAN fibres. As a result, mixtures containing 6% Dolanit 11 retain their workability better than mixtures containing 3% E-glass and Dolanit 10.

If there is a continuous supply of water to the concrete or cement during hydration, cement expands due to water absorption by the cement gel [5].

As it is shown in Figure 4, E-glass and Dolanit 11 decreased the amount of FRC expansion when they were used in 1% and 3% volume fractions, respectively. But inclusion of Dolanit 10 increased swelling of FRC in all volume fractions in comparison to that of cement alone. By further increasing of E-glass and Dolanit 11, the trend of changes of swelling was reversed so that swelling became higher than that of cement with no fibre.

As mentioned before, withdrawal of water from hardened cement or concrete stored in unsaturated air causes drying shrinkage [5]. Figure 5 shows that fibre inclusion has a positive effect, that is, inclusion of fibre and increasing its volume fraction result in decreasing the amount of the composite's drying shrinkage. For every volume fraction, the effectiveness of Dolanit 10 in reducing drying shrinkage is more than that of the two other fibres.

**CONCLUSION**

Polymeric fibres could improve the impact strength of cementitious composites significantly. For instance, impact strength of cementitious

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**Fig. 5.** Drying shrinkage of cementitious composites after 28 days exposure to dry air as a function of volume fraction of different reinforcing fibres.
composites reinforced with 6 volume percent of Dolanit 11 was 7 times greater than that of cement itself.

While the compressive strength of the cement was only slightly improved by inclusion of E-glass and Dolanit 11, it was decreased by incorporation of Dolanit 10.

Addition of fibres decreased the flowability of cement mixture due to interlocking of fibres in fibre reinforced cementitious composites and therefore making moulding of cement composite more difficult than cement with no fibre.

While E-glass and Dolanit 11 slightly decreased the amount of expansion when used in volume fractions of 1% and 3%, respectively, inclusion of Dolanit 10 increased expansion in comparison to that of unreinforced cement.

The effect of Dolanit 10 in reducing the amount of drying shrinkage was more than that of the other fibres. Drying shrinkage of cementitious composites reinforced with 3 volume percent of Dolanit 10 was 50% less than that of cement with no fibre. As a result, fibre inclusion in cement lowers the size of crack width arising from drying shrinkage.

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