Effect of Wollastonite micro fiber addition in mortar and concrete mixes

Shashi Kant Sharma, G.D.Ransinchung R.N., Praveen Kumar

Abstract—Concrete and mortar though are same units, made of same kind of material, but still there is a lot of difference in their properties. We can say that a lot of properties depend upon mortar paste, for example: strength, flow, workability; but addition of aggregates play an important role due to the formation of a transition layer between them and mortar. The strength of concrete in that case, may be more, equal or less than the mortar, depending upon the strength of interface. If another material, like a microfiber is introduced above that, then the property of concrete changes significantly. The microfiber acts at the interface of cement-sand and mortar-aggregate and reinforces the frontal process zone present, there itself. This reduces the shrinkage of composites thus making them quasi brittle. In this study experimental results show that, flexural strength which is an indicator of shrinkage resistance of cement composites, improves with the addition of wollastonite micro fiber. It is beneficial to take wollastonite microfiber and silica fume in ratios between 2:1 to 3:1. About 27.5% cement replacement can be achieved by wollastonite micro fiber addition. Also it was found that, in concrete, the rate gain of flexural tensile strength and compression strength with age was lower by about 60% and 30% as compared to the same rate gain in mortar.

Index Terms— Flexural, Frontal Process Zone, Interfacial Transition Zone, Microfiber, Quasi Brittle, Reinforce, Shrinkage

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1. INTRODUCTION

CEMENT composites are basically designed for two qualities: strength and durability. Although strength is a major factor which determines the performance of composites but durability should be taken into account to mitigate the deterioration caused by environmental and rheological factors.

Two well known such factors are creep and shrinkage, which cause the deterioration of composites by the formation of cracks. Their effect, added by fatigue strains at loading (depending upon strength performance under loading) lead to the growth of cracks in cement composites. Although they appear to work hand in hand, but it is the cracks produced at initial stage of setting and curing of composite mixes, which starts the process of crack formation. Hence, the micro cracks formed by shrinkage and creep are the foundation factor for pavement deterioration.

Initial flaws are always present in any cementitious material, whether it is a plain cement paste specimen or fiber-reinforced cement composite (FRCC). When load is first applied to the FRCC, areas of stress concentration develop at the tips of the initial flaws. With additional loading, microcracks form (or initially present) and grow in the frontal process zones ahead of the crack tips. It is assumed that the initial flaw will extend into the microcracked region when the microcracking has reached a saturated level [1].

With proper incorporation of fibers, the failure mode of cement composites can change from brittle to quasi-ductile ([2], [3], [4], [5]). The toughness of the material (measured, for example, from the area under a complete load-displacement curve) can also be significantly increased. In all the composites, fibers influence the fracture processes ahead of the crack tip in the frontal process zone (FPZ) and behind the crack tip in the crack bridging wake (shown in fig. 1). It is what happens in the FPZ that determines the first crack strength of the composite. Preventing the formation of the first crack is highly desirable in the design of durable thin sheet, fiber-reinforced cement composites.
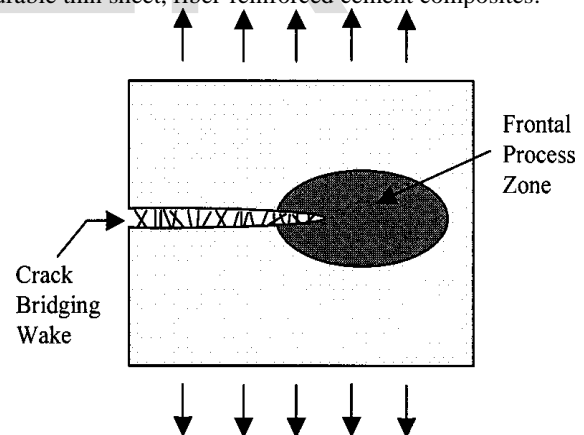

Fig. 1 Crack formation in cement composites (P.K Nelson et al. 2002)

It is interesting to know that irrespective of the type of composite, fibers improve its behaviour but the level of improvement at each position is different for different composites. This too depends upon the type of fibers and their geometry. For a thin sheet fiber reinforced cement concrete having initial flaw of approximately 60 μm, fibers with diameter <30 μm will be deemed micro diameter fibers. Generally microfibers are fine fibers with lengths less than 10 mm and diameters in range 25-40μm. With their high specific surface areas (>200 cm^2/g), they provide a large number of fibers in a

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given section of the composites and thus furnish more effective reinforcing mechanisms at the microcracking level (cracking due to thermal and mechanical shrinkage).

Application of Microfiber Reinforced Mortar and Concrete

Repair works suffer from debonding and spalling of concrete layer. The major reasons often cited for debonding and spalling of repairs are differential thermal movements, elastic incompatibilities, shrinkage stresses, occasional impact; rebar corrosion, substrate deficiencies, frost action, and poor workmanship ([6], [7], [8], [9]). These same reasons are responsible for cracks in an otherwise, a simple concrete pavement topping. Given these reasons for spalling and debonding of repairs, durable thin repairs (less than 25 mm thick) are particularly difficult to achieve. For a durable repair, the desired characteristics of the repair material include low permeability, a high tensile strength, adequate impact resistance, sufficient deformability (ductility), high fracture toughness, low shrinkage, good dimensional stability, good abrasion resistance, and most of all, a strong tensile and shear bond with the base concrete. For thin repairs, however, the maximum dimensions of both the aggregate particles and the fibers have to be limited. Consequently, for thin repairs, the use of cements concrete and mortars reinforced with microfibers is conceivable.

2. EXPERIMENTAL PROGRAM

It consists of two parts: testing of pastes, mortars and then testing of concrete. With shrinkage there is a loss of flexural strength of cement composites, even though the strength may not be affected to a considerable extent. Hence this test has been performed at 28 and 56 days to serve as an indicator of shrinkage cracks produced due to drying (hydration).

2.1 Paste and Mortar Testing

Fresh state tests like, normal consistency, initial and final setting time tests (IST and FST) were performed on four blended pastes and one normal cement (OPC 43 grade) paste. The blends were made by replacing cement with silica fume (0, 7.5% by weight) and wollastonite micro fiber (10, 20, and 30% by weight) respectively in all mixes. In all five mixes were tested: pure cement mix, cement plus wollastonite micro fiber and three mixes of ternary combination of cement with wollastonite micro fiber and silica fume. Mortar mixes were then prepared on the basis of water demand obtained from the normal consistency test, having 1:3 proportion of cementitious material: sand. IS 4031 (Part 6):1988 and IS 516:1959 were followed to perform compression and flexural strength test respectively. For mortar cubes of $7.06 \times 7.06 \times 7.06$ cm^3 were cast and tested after 7, 28 and 56 days at a uniform and steady load of 35N/mm^2/min. Beams of size $10 \times 10 \times 50$ cm^3 were cast and tested after 28 and 56 days of curing, at a steady and uniform loading rate of 180 kg/min.

2.2 Concrete Test

The test specimens consisted of 150×300mm cylinders, and $100 \times 100 \times 500$mm prisms made of concrete mix M 40 having water/cementitious material ratio of 0.40. Wherever required, superplasticizer (NSF) was added to bring the slump value between 50-100mm. About 0.25% and 0.5% (by weight of cement) superplasticizer was added in X2 and X3 mix to do the same.

The cylinders were used for compressive strength tests, the prisms were tested for flexural strength. The cylinders were cast using 150×300mm plastic molds. The prisms were cast using Plexiglas molds. After casting, the specimens were stored at room temperature for 24 hr. They were covered with plastic sheets to minimize evaporation loss. After 24 hr, the specimens were removed from the moulds and cured for 7,28 and 56 days in a room maintained at 100 percent relative humidity and a temperature of 23°C+/-2°C. IS 516:1959 was followed to perform both compression and flexural strength test. Compression strength test was performed on three cube samples per mix and their average value was taken as compression strength of mix. Modulus of rupture was obtained using the prisms supported over a simply supported span of 400 mm, at 28 and 56 days. Loads were applied at middle third points. The loads applied were measured using a set-up, shown in fig.2, which eliminated the extraneous loads.
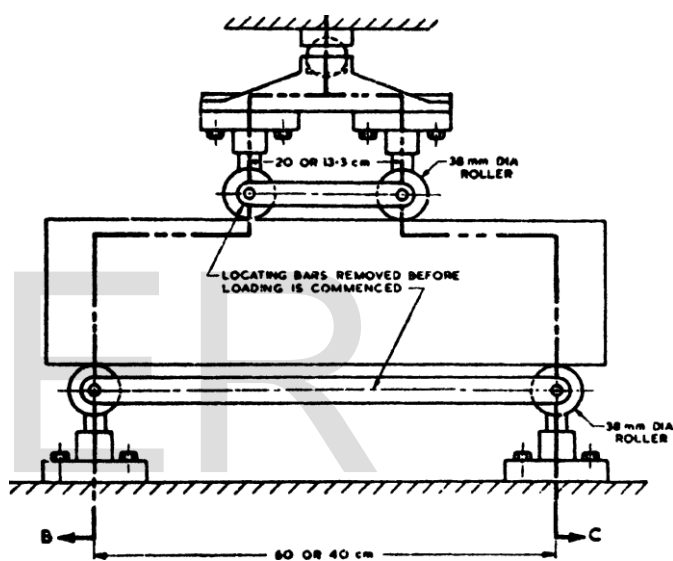

Fig. 2 Setup for performing flexure strength test (IS 516:1959)

3. RESULTS

3.1 Paste and Mortar

Table 1and fig. 3 give the percentage composition of mixes along with its constituents in (kg/cubic metre) and fresh state properties of cement composites. It was found that both wollastonite micro fiber and silica fume increase the water demand, IST and FST of cement pastes. At their equal ratios, the mix starts loosing plasticity very early (earlier than cement) and even sets somewhat earlier (earlier than other blends) with respect to pure cement or cement plus wollastonite microfiber mix. Therefore chances of shrinkage are more for this ratio. For ternary blends, upto the ratio 2:1 (WMF: SF) IST and FST increase and then drops. X2 marks the transition stage of properties. Since water demand drops after X2, therefore chances for shrinkage reduction are more between 2:1 to 3:1 ratios of these materials.

TABLE 1 PERCENTAGE COMPOSITION AND FRESH STATE PROPERTIES OF MIXES.

Mix	Composition (%age) (C+WMF+SF)	Consistency	IST min.	FST min.
C0	100	29	150	220
W0	90+10	30.5	170	255
X1	82.5+10+7.5	32	140	249
X2	72.5+20+7.5	34	159	284
X3	62.5+30+7.5	35.5	152	275

TABLE 2 MECHANICAL TEST RESULTS OF MORTAR

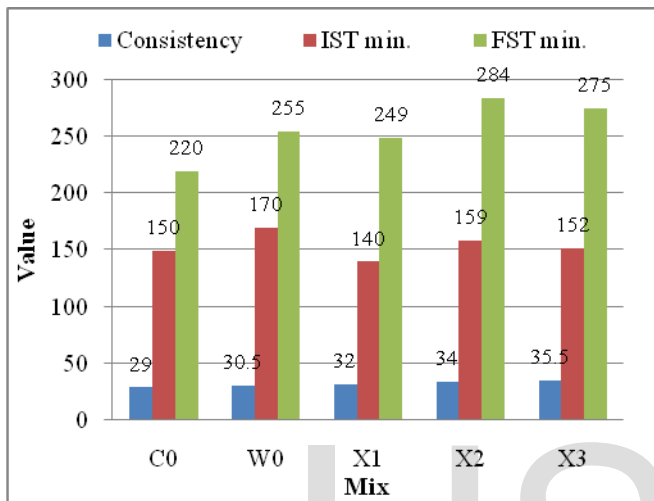| Mortar Mix	Compression strength (N/sq mm)			Flexural strength (kg/sq. cm)	
	7days	28 days	56 days	28days	56 days
C0	32	44	54	18.8	20.1
W0	29.5	36	40	14.2	15.7
X1	31	48.5	54	17.2	19.0
X2	26.5	38	42	15.2	17.6
X3	17	28.5	31.5	13.2	16.0

Fig. 3 Bar chart showing comparison of setting times with water demand for mortar mixes
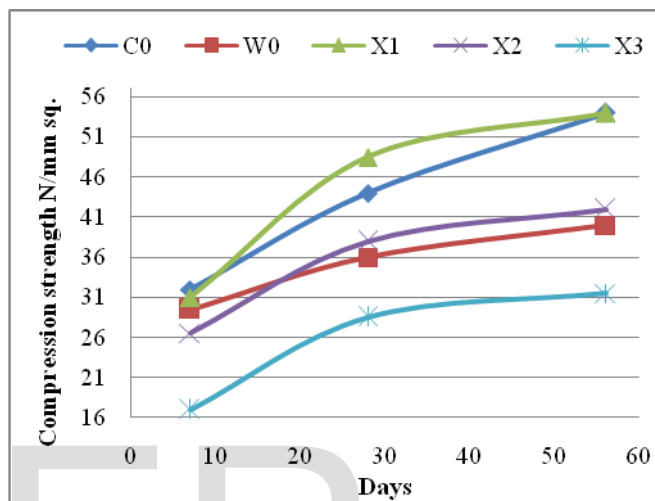

Fig. 4 Graph showing compression strength gain of mortar with age

Table 2, fig. 4 and fig.5 give the compressive strength and flexural strength result with the respective duration for mortar mixes. In general, with an increment in wollastonite micro fiber content, compression and flexural strength decrease to a small extent due to replacement of cement, but, with the addition of silica fume these values become comparable to those of pure cement mixtures. Even the strength of X1 mix becomes nearly equal to normal (pure cement) mix. In terms of percentage strength gain with age, it was found that, with an increment in wollastonite micro fiber content, there was an apparent increment in flexural strength whereas compression strength found large decrement, when the mixes were compared with normal mix at 56 days. It was also found that silica fume addition led to a decrement in flexural strength increment rate at lower wollastonite micro fiber content. At higher wollastonite micro fiber content the flexural strength rose to more than 20% for X3 combination, with the ageing of mixes from 28 to 56 days. The possible reason could be refinement of pore structure by pozzolanic action of wollastonite micro fiber, in addition to its fiber action. Also there may be reduction in interstitial voids at higher ratios (greater than 2:1) of wollastonite-silica fume combination.

Compression strength on the other hand, increased maximally by 11.4% for X1 and; for other mixes it was nearly 10% only.
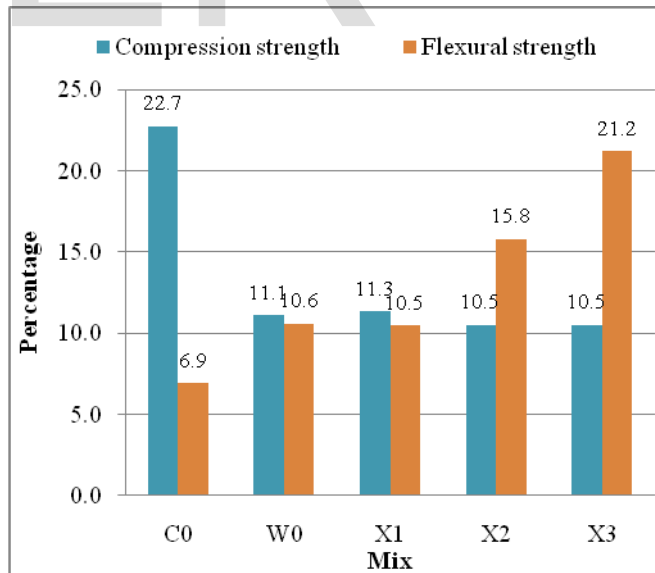

Fig. 5 Bar chart showing percent increment in compression and flexural strength of mortar with age (28-56 days)

3.2 Concrete

Table 3, fig. 6 and fig. 7 provide the test results for concrete, for both types of mechanical tests. In general, with the introduction of wollastonite micro fiber in concrete, the compression strength

and flexural strength do show increment, but it may reduce at higher wollastonite micro fiber content, due to higher cement replacement. With addition of silica fume this trend is ascending in nature, with X1 and X2 mix showing higher compression and flexural strength. Hence silica fume addition complements high higher replacement of cement with wollastonite without any strength loss. In terms of percentage strength gain with age, wollastonite micro fiber addition with silica fume increased the compression strength apparently and a partial increment in flexural strength was found upto X2, when the mixes were compared with normal mix. With the increment in age, both compression strength and flexural strength increased by 8%, maximally for X1 combination, whereas compression strength was little lesser at 7.8% for X2 combination. Same factors are responsible for the improvement in the properties of these mixes alike mortar, but the difference in flexural strength improvement rises due to limited fiber action in concrete by wollastonite microfibers. Hence pore size improvement is a major factor apart from fiber action, which improves flexural strength.

TABLE 3 MECHANICAL TEST RESULTS FOR CONCRETE

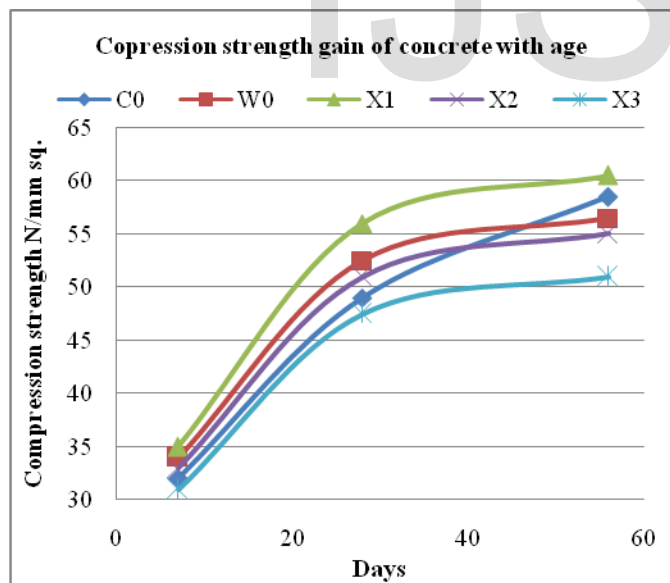| Concrete	Compression strength (N/sq mm)			Flexural strength (kg/sq. cm)	
Mix	7days	28 days	56 days	28days	56 days
C0	32.0	49.0	58.5	43.6	47.1
W0	34.0	52.5	56.5	49.3	53.2
X1	35.0	56.0	60.5	52.8	57.0
X2	33.0	51.0	55.0	48.5	52.4
X3	31.0	47.5	51.0	42.8	46.2

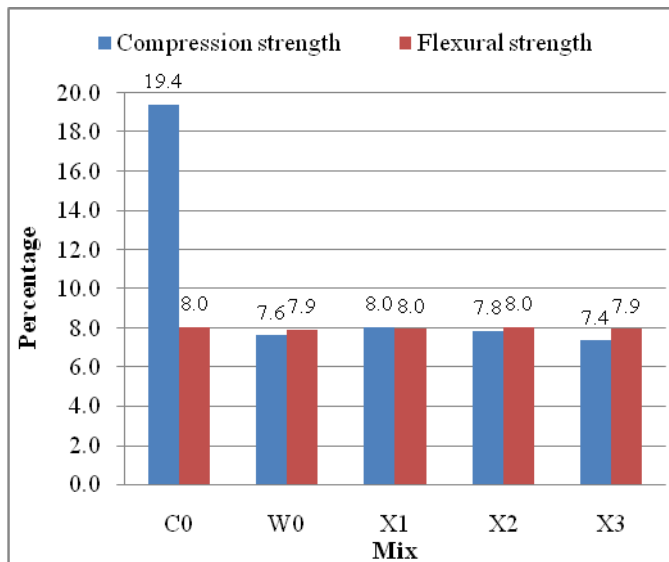Fig.6 Graph showing compression strength gain of concrete with age

Fig. 7 Bar chart showing percent increment in compression and flexural strength of concrete with age (28-56 days)

4. CONCLUSION

For mortar, higher ratio of wollastonite micro fiber-silica fume combination can be taken, whereas for concrete, larger replacements are avoidable (maximum value of 27.5% only). Also wollastonite-silica fume ratio should lie close to 2:1. Water demand, IST and FST also recommend the use of this ratio. Also, the rate of flexural tensile strength and compression strength gain in concrete, was lesser than 60% and 30% respectively as compared to the same gain in mortar.

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