COMPARATIVE STUDY OF MECHANICAL PROPERTIES OF STEEL WOOL AND POLYPROPYLENE FIBRE REINFORCED CEMENT MORTAR COMPOSITES

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Abstract – *In the current study a comparative analysis of the mechanical strength of steel wool and polypropylene fibre reinforced cement mortar slabs is presented. For this work two fibre contents of 0.75 % and 2 % of the cement mass were used. A total of 60 slabs including the control specimens, of dimensions 300 mm x 300 mm x 20 mm was cast and tested at 14 and 28 days after curing. Impact strength tests were conducted on 30 specimens, while the remaining slabs were subjected to flexural strength tests. In either case, 3 slabs were utilized to obtain mean values per test parameter. It was found that the unreinforced slabs had very low impact resistance after the initial cracking. Furthermore, there was little difference between the impact load resistance of the steel wool fibre reinforced slabs and the control specimens. In contrast the polypropylene fibre reinforced slabs performed significantly better as regards impact load resistance and the distribution of crack patterns. With reference to flexural strength, both types of fibre reinforced specimens exhibited similar behaviour and response. However, as far as toughness corresponding to the recorded deflections at failure was concerned, it was concluded that the steel wool mortar composites were relatively tougher than their polypropylene counterparts.*

Key Words: Steel Wool, Polypropylene, Fibre, Impact, Flexural, Strength

1. INTRODUCTION

Cement mortars have been universally employed for a variety of purpose in building and civil engineering, ranging from plastering, rendering, repair of damaged concrete, floor levelling and filling or patching. These uses notwithstanding, it is commonly accepted that cement mortars have several limitations including delayed hardening, quite low tensile strengths, high drying shrinkage as well as relatively low chemical resistance. It is for these reasons that in recent decades cement mortar composites have come into favour. Such composites comprise cement, sand, water and fibres. With reference to the latter, both natural and artificial fibres are employed to enhance flexural strength, impact resistance, ductility and toughness. According to Ramakrishna and Sundararajan [1], the fibres are also important in reducing the bleeding, shrinkage and permeability of the cementitious matrix in the fresh state.

Although steel fibres first came into being in modern civil engineering, synthetic fibres particularly polypropylene have become increasingly popular. In fact both types of fibres are now very widely used (Naaman et al. [2]). In recent decades there have been numerous studies conducted on fibre reinforced concrete composites. These have been succinctly summarized by Zollo [3], ACI Committee 544 [4] and Brandt [5], amongst others. More recent works are those due to Mobasher [6], Uddin [7], Singh [8], Naaman [9] and finally the RILEM-FIB publications ([10], [11]) on fibre reinforced concrete. A survey of the literature reveals that arguably more studies have been carried out on fibre reinforced concrete composites, in comparison to fibre reinforced cement mortars. It is for this reason and to highlight the benefits of using synthetic fibres, more especially polypropylene fibres, that the present investigation has been conducted. The emphasis is on the utilization of materials sourced locally or at least within the Southern African region. A study of the impact and flexural strengths of steel wool and polypropylene fibre cement mortar composites has been attempted.

2. EXPERIMENTAL PROGRAMME

In this section the basic characteristics of the major materials utilized, the manner in which the mix proportions were chosen as well as some details regarding casting of the composite specimens are presented. In addition the testing procedures adopted are outlined to some degree.

2.1 Materials, Mix Proportions and Casting

The steel wool fibres utilized were purchased locally. They were of very fine grade and had elastic modulus of 200 GPa and low carbon content. Diameters ranged from 6.35 μm to 8.89 μm, and tensile strengths were in the range 200–300 MPa. The polypropylene fibres had diameter 18 microns and fibre lengths of 12 mm. They possessed high acidic resistance and 100 % alkali resistance. The cement used was masonry cement MC 12.5 X required to produce a Class 1 mortar as specified in Fulton's Concrete Technology [12], with a minimum 28 day compressive strength of 12.5 MPa. The sand constituent in mortar is by far the major constituent of sand-cement mixes and has a significant influence on their performance. Consequently, natural sand was employed as this was generally rounded and ideal for good workability. The sand met the recommended grading for mortar sands as specified in Fulton's Concrete Technology [12]. Samples of the steel wool fibre and the polypropylene are shown in Figures 1 and 2 respectively.

Fig. 1: Sample of steel wool fibres

Fig. 2: Sample of polypropylene fibres

A Class 1 mortar as specified by SANS 1090: 2002 [13] was used. The mix had a cement- sand ratio of 1:1.6. The water-cement ratio was deduced by trial mixes, the aim being to achieve a medium workability mix that would be kept constant for all the proposed tests on flexural and impact strengths. A water-cement ratio of 0.47 was ultimately adopted, and this was maintained for the casting of all 60 slabs, each being of dimensions 300 mm x 300 mm x 20 mm. All parameters were kept constant except for the varying fibre percentages. The cast specimens were vibrated by means of a vibrating table for a specified period and subsequently covered in wet hessian for 24 hours. They were thereafter de-moulded and then immersed in a temperature regulated water bath containing clean potable water. Of the 60 slabs cast, 30 were cured for 14 days while the remaining was cured for 28 days prior to testing. The composition of the mortar mix used for the experimental programme is shown in Table 1.

Table -1: Mortar composition for casting three slabs

Fibre content (%)	Sand (g)	Cement (g)	Water (ml)	Fibre (g)
0	7800	5025	2400	0
0.75	7800	5025	2400	38
2.0	7800	5025	2400	101

2.2 Testing Procedures

The cured samples were tested immediately after they had been removed from the curing tank and hand dried with paper roll or dry cloth. Both the impact strength and flexural strength tests were carried out on the steel wool and polypropylene fibre reinforced specimens with fibre variations of 0 %, 0.75 % and 2 % at 14 and 28 days after curing. For the impact tests, a solid steel metal ball weighing 440 g was dropped from a height of 330 mm unto the test specimens. The ball was allowed to first roll down a gently inclined slope before it fell, in order to maintain the same force (or energy) for each drop. The incline was so minimal that the extra distance the ball rolled prior to falling vertically was deemed insignificant. The ball was also positioned such that it landed exactly at the centre of each test slab; the latter was simply supported on all four edges. The number of blows it took to observe the first crack (which was ascertained visually and checked for after each drop), and the number of blows it took for ultimate failure of a specimen were recorded. Ultimate failure was defined in this context as when the crack went right through the thickness of the slab. The test set-up for the impact testing is shown in Figure 3.

Fig. 3: Impact strength test set-up

The flexural strength for the slabs was determined using a one-point loading system by means of a 150 kN capacity flexural testing machine. The specimens' were placed in position supported on two opposite edges. The load from the flexural testing machine was applied at a slow rate and the dial gauge readings were recorded simultaneously with the load causing deflections. The experimental set-up for the test is shown in Figure 4.

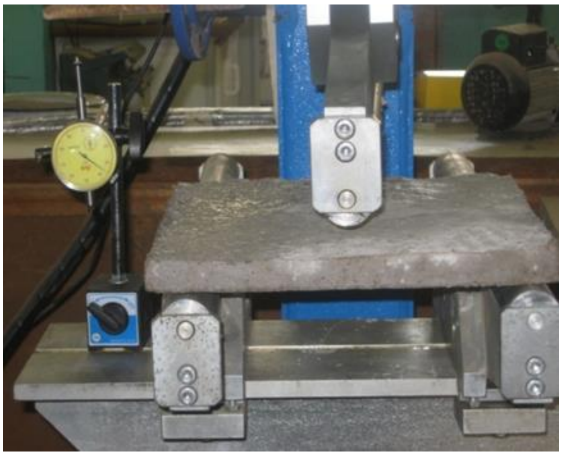

Fig. 4: Flexural strength test set-up.

3. RESULTS AND DISCUSSION

In this section the results of the impact and flexural strength tests are presented, together with the crack patterns observed during loading. In addition cogent observations and deductions are made

3.1 Impact Strength Tests

It had been observed that 2 out of every 3 specimens of the unreinforced cement mortar slabs developed cracks prior to placement in the curing tanks. These were identified as shrinkage cracks because they were hairline shaped, random, multiple, meandering in the concrete, and formed a discontinuous pattern. Notwithstanding, the variation of the number of blows with fibre fraction for first cracking and for ultimate failure at 14 and 28 days, for the steel wool and polypropylene fibres are shown in Figures 5 and 6.The results indicated are the average values for three slab tests. For the 100 % mortar slabs (or 0 % fibre content), 6 blows of the steel ball (equivalent to 7.92 Joules) caused initial cracking at 14 days. The longer curing period of 28 days resulted in very little extra resistance to impact loading as only a single extra blow (or 1.32 Joules) was required to initiate the first cracking. For the 28 days test, 8 blows in total were needed to produce ultimate failure. This implies that unreinforced mortar slabs have relatively very low impact resistance after the initial crack.

For the steel wool fibre specimens, there was little deviation between their impact load resistances and those of the unreinforced mortar slabs, although in the former, no shrinkage cracks were observed at the initial stages. There was not much variation between the 14 and 28 days curing test results, although for the 2 % fibre fraction, the number of blows required from first cracking doubled, in order to produce ultimate failure.

With regards to the 14 or 28 days test, the introduction of polypropylene definitely enhanced the mortar quality because 0.75 % of polypropylene reinforced mortar resisted at least 13 drops of the steel ball (or 17.2 Joules) before initial cracking was observed. After this crack, at least 100 additional blows caused ultimate failure. This was on account of the superior matrix the fibres created. They assisted in holding the mortar together by distributing the shock loading evenly through the slab. This can be seen from the crack patterns which are discussed at a later stage in the present section. However, an increase in the polypropylene fibre content to 2 % did not increase the amount of energy required to initiate a crack. For both the 0.75 % and 2 % fibre contents, the impact resistance after initial cracking was significantly high, since it took from 132 to 153 Joules to cause ultimate failure in the slabs.

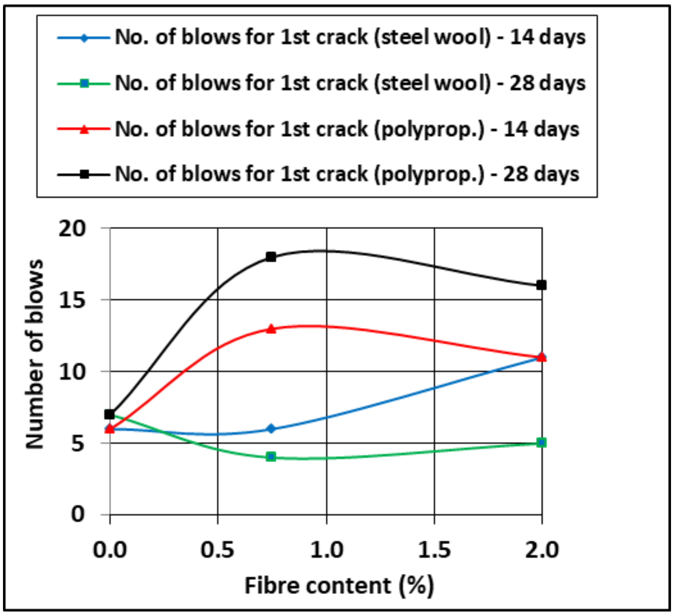

Fig. 5: Variation of number of blows with fibre fraction

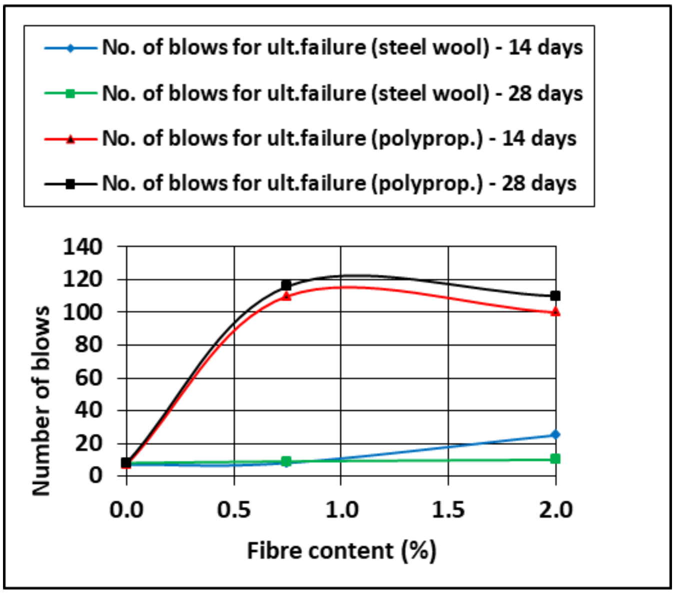

Fig. 6: Variation of number of blows with fibre content

The residual impact ratio for the unreinforced cement mortar slabs never exceeded 1.2 for both the 14 day and 28 day tests. In respect of the steel wool fibre specimens the range was 1.3 – 2.3, which at most was approximately twice that of the unreinforced mortar slabs; this was certainly unimpressive. The polypropylene specimens in contrast exhibited excellent characteristics, since the residual impact ratios were in the range 6.4 – 9.1.

3.2 Crack Patterns

Typical crack patterns at failure are shown in Figures 7 to 9. For the unreinforced slabs the initial cracks appeared at the bottom across the slab specimens. Application of further impact loading caused the crack to lengthen and widen until it went right through the slab depth, resulting in ultimate failure. The steel wool reinforced slabs had crack patterns that resulted in 3 to 4 broken pieces. The cracks formed were more like those of their polypropylene counterparts, but were not as many.

For the polypropylene reinforced slabs, the crack patterns were quite different from those of the unreinforced slabs. The initial crack at the bottom of the slabs was extremely small and hair-line, requiring close visual inspection to spot. Multiple cracks would form around the struck region and widen slightly, meandering towards the slab edges, as further impact loading took place. The failed slab would consist of multiple dismantled slab pieces.

Fig. 7: Failure pattern for unreinforced slab

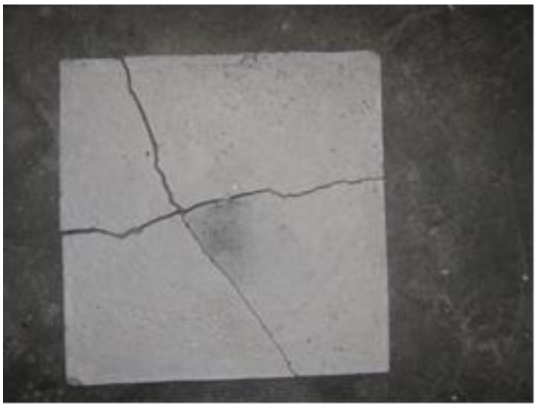

Fig. 8: Crack pattern for steel wool fibre slab

Fig. 9: Cracks for polypropylene fibre slab

3.3 Flexural Strength Tests

Load–deflection curves for the steel wool fibre reinforced specimens and the unreinforced mortar slabs at 28 days are shown in Figure 10; the 14 days test results are not presented. The unreinforced slab withstood a force of about 2.1 kN with a corresponding deflection of 2.1 mm for the 14 days test. The 28 days test produced a slight increase in ultimate load to about 2.32 kN; this gave rise to increased deflections by about 0.53 mm. The 0.75 % steel reinforced mortar slab exhibited about 1.31 kN more load resistance at 14 days than the unreinforced slab. An increase in steel content to 2% resulted in about 1.89 kN load resistance at 14 days. The 28 days test produced an increase in load resistance but resulted in a decrease in deflection in the range 0.75–0.81 mm. On the whole the steel wool fibre slabs had increased load resistance over the unreinforced specimens by 1.31–1.89 kN at 14 days, and 0.94–1.23 kN at 28 days. Considering the fact that these slabs were of 20 mm thickness and subjected to one central point loading, these increases were considered significant.

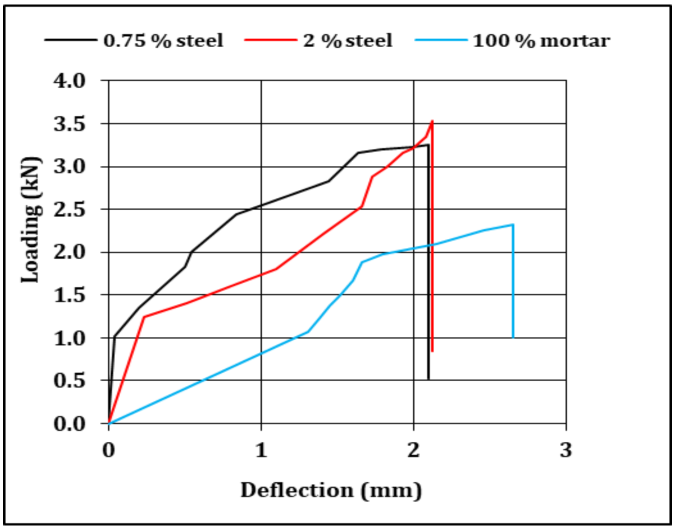

Fig. 10: Load-deflection curves–steel wool slabs at 28 days

Load-deflection curves for the polypropylene fibre reinforced specimens at 28 days are shown in Figure 11. The behaviour of these slabs were rather different from that of the steel wool specimens, in the sense that for the 14 days test, an increase in fibre content from 0.75 % to 2 % resulted in a decrease in the load capacity from 3.69 kN to 2.85 kN. However for the 28 days test, the trend was reversed; an increase in fibre content from 0.75 % to 2 % resulted in an increase in failure load from 3.25 kN to 3.54 kN. This was rather odd and could be due to poor mixing and spreading of the 0.75 % polypropylene fibre fraction throughout the mix, or some other unknown factors.

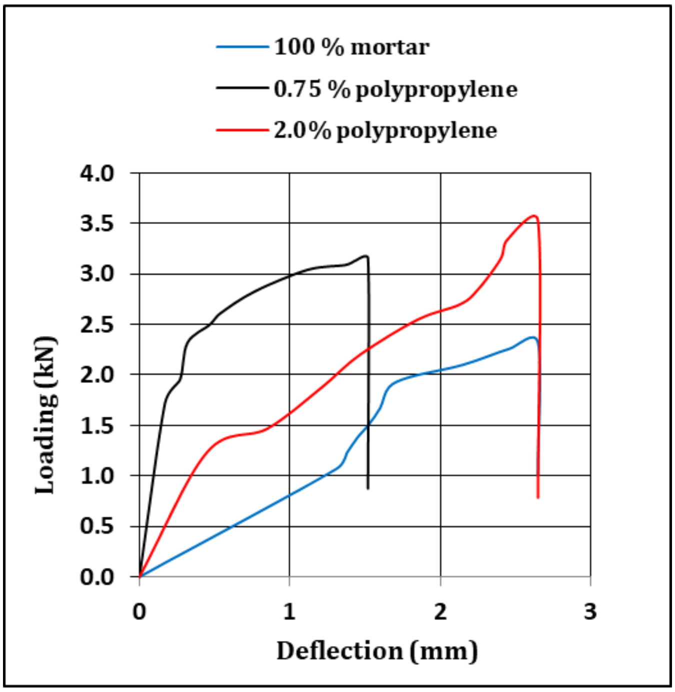

Fig. 11: Load-deflection curves for polyprop fibre slabs

Calculations for toughness indicated that the steel wool fibre reinforced mortars were tougher than the polypropylene equivalents. At 28 days a toughness of up to 5.07 Joules and 3.71 Joules was obtained for the steel wool and polypropylene fibre reinforced slabs for the 0.75 % fibre fraction. For the 2 % fibre fraction at 28 days the respective values were 3.95 Joules and 4.94 Joules respectively. As expected, the unreinforced slabs exhibited the least toughness of 2.60 Joules at 28 days.

4. CONCLUSIONS

The present investigation was intended to be a comparative study of the mechanical strength of steel wool and polypropylene fibre cement mortar slabs. For this purpose, a total of 60 slabs were tested under conditions of impact strength and flexural strength loadings. Based on the experimental work carried out, the following conclusions may be drawn.

(1) Slabs reinforced with polypropylene fibres withstood the highest amount of impact blows after the initial crack, up unto ultimate failure. In addition, the crack patterns in the polypropylene reinforced slabs were more varied, widespread and developed than those for the steel wool fibre reinforced specimens.

(2) The steel wool and the polypropylene fibre reinforced slabs had comparable flexural strengths. The toughness of the steel wool fibred slabs was much higher than the polypropylene fibre specimens for the 0.75 % fibre fraction. However for the 2% fibre content, the situation was somewhat reversed.

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