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DUCTILITY AND STRENGTH OF REINFORCED CONCRETE BEAMS INTRINSICALLY REINFORCED WITH POLYPROPYLENE FIBRES

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ABSTRACT

One of the horizons through which a more cost effective concrete can be conceived and be able to satisfy constructional requirements as well as modern society's demand, would be the Green Concrete concept. It has been for decades that sustainable design is drawn into direct attention of different sectors of society. From the structural point of view, the invaluable goal of this project is to improve the ductility of the concrete structural element which helps eliminate or reduce the need for steel reinforcement in concrete structures. Trend of improvement in human knowledge is promising and so far this project, like other projects with the same aim, is contributing to inevitable changes in the construction industry. Cracking in reinforced concrete causes stiffness reduction which is the reason for decreasing the capacity of the structure in bearing structural loadings. Concrete is a brittle material and its failure is mostly due to this characteristic. Different methods have been used to overcome this problem and give ductility to concrete matrix. Using short fibres like steel fibres or synthetic fibres and polymeric material is of attention to improve this behaviour of concrete. The effect of these additives is more on the post peak behaviour of concrete which improves the strain softening where tension is applied. Fibres within the matrix, can bridge the cracks which improves the performance of concrete matrix and results in a better stress bearing material. Different types and percentages of polypropylene fibres have been investigated for the mechanical properties of concrete. From among these mixes two best are selected and reinforced beams are casted to be tested under four point bending test. Results show that by using high percentage of PP fibre in the reinforced concrete beam, ductility can be improved by 160 %.

Keywords: Ductility, fibre reinforced concrete, Polypropylene fibre.

1. INTRODUCTION

In order to model and evaluate the behaviour of concrete, it is important to know some special parameters such as stress strain curves under given loading regimes, compressive strength, etc. Cracking in reinforced concrete causes stiffness reduction which is the reason for decreasing the capacity of the structure in bearing structural loadings. Concrete is a brittle material and its failure

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mode is due to this characteristic. Different methods have been used to overcome this problem and give ductility to concrete matrix. Using short fibres like steel fibres or synthetic fibres and polymeric material is of attention to improve this behaviour of concrete. Adding supplementary material to the concrete mix can significantly improve the ductile behaviour and reduce crack propagation (Hamoush, Abu-Lebdeh et al. 2010). The effect of these additional materials is more on the post peak behaviour of concrete which improves the strain softening where tension is applied. Fibres within the matrix, can bridge the cracks which improves the bond between concrete matrix and results in a better stress bearing material.

As mentioned, using fibre in concrete matrix is of interest to researchers. Li and Zhang (Li VC 2002) studied the performance of a special engineered cementitious composite using fibres which led to a high performance mix with high tensile behaviour. It is claimed to have been able to achieve a tensile strain of 3-5%, which is relatively high compared to a normal concrete and can be used in pavement overlays. They observed that both the load carrying ability and deformability of engineered cementitious composite overlay were significantly higher than that of plain concrete overlaid systems. After the first crack happens fibres cling to the matrix and prevent the crack from opening. This is where more energy should be spent to either break or pull out the fibres. Therefore toughness increases and the bearing capacity after cracking increases. The post peak behaviour of concrete has been investigated by different researchers. A study on the post peak response of concrete beam (Jin Keun & Tae Gyu 1992) showed that concrete exhibits a softening behaviour that gradually decreases with increasing displacements due to a strain softening. In strain softening materials, the effect of strain softening in stress wave propagation has been studied (Read & Hegemier 1984). It is observed that for incrementally linear models, strain-softening occurs when the matrix of tangent stiffness is definite and the softening curve can be obtained from the load deflection curves under tensile tests.

2. EXPERIMENTAL PROGRAM

2.1. Material and mixes

18 mm long monofilament and 19 mm long fibrillated PP fibre, with diverse percentage volumes were studied in this project. These mixes also include the addition of 30% FA as partial replacement of PC and utilisation of manufactured coarse and fine sands to replace natural coarse and fine sand, respectively, to aim for producing a ‘greener’ concrete.

Beams of the selected FRC with addition of reference beams is moulded and cured for a designated ageing period. The 4 point test is a popular static test to study the flexural, compressive and tensile behaviour of structural members under load. The four-point load test is the main method employed to evaluate the static performance of the concrete beams. Two beams (PF1% and PM0.25%) were moulded for each selected mix. They have been tested (4-point load test) to determine the flexural capacity. The test is carried out after a minimum of 56 days ageing due to

30% addition of FA as partial replacement of PC (the ultimate strength of FA concrete would have further increased in this timeframe). Linear variable differential transformers (LVDTs) is installed to measure the deflection of the beams in middle section.

2.2. Test setup and instrumentation

The test set up in this project was a simply supported beam carrying double concentrated point loads at each 1/3 of the beam span. The load deflection history of a reinforced beam consists of the inelastic range (uncracked section), elastoplastic range (cracked section) and plastic range. For plotting the load deflection diagram of the reinforced beam, LVDT data obtained from the middle section is used. A beam containing CF mix (with 30% FA), a beam containing 25% monofilament PP fibre in the CF (which is the PM0.25% mix ID) and a beam containing 1% fibrillated PP fibre in the CF mix (which is the PF1% mix ID) have been prepared and tested.

3. RESULTS AND DISCUSSION

Data from tests pertaining to the fresh properties of FRCs are presented in Table 1 showing the fresh properties of mixes containing PP fibres. The amount of cementitious material as well as aggregates, water, HWR, fibres are detailed before. The amount of HWR used in each mix has been different as a slump of 80mm was targeted. Mass per unit volume of the concrete mixes has also been measured to have the volume density of the engineered concrete. Usually, the volume density of conventional concrete is approximately 2,400 to 2,500 kg/m3; this property is measured then to evaluate the effects of fibre on concrete density and also use this value for further calculations. Air content is also measured and presented. Knowing the amount of entrapped air in the concrete helps with quantitative analysis of the test results and may help explain certain behaviour of the concrete mix. Results of Table 1 show that, the amount of HWR used in monofilament containing mixes was much higher than that of fibrillated fibres which show that monofilament PP fibres decrease the workability of the mix more than fibrillated PP fibres.

Table 1: Fresh Properties.

Mix ID	W/C	Slump (mm)	HWR (ml/ m^3)	AC (%)	Volume Density (Kg/m^3)	Compressive strength (MPa)
CF	0.35	75	1000	1	2450	80.0
PM0.25	0.35	60	1923	1.8	2380	76.5
PF1	0.35	65	1846	1.5	2290	71.8

Results of compressive tests are illustrated in Table 1. Regarding the effect of PP fibres on hardened properties of concrete some conclusions are presented. Due to the presence of FA in the mixes, all compression tests were also performed to obtain 56 day compressive strength. Considering the compressive strength properties it is observed that in FRCs, 0.25% of monofilament PP fibre has reached the 56 days compressive strength in earlier age comparing to the control concrete. In lower percentages (0.25%), PP fibres have contributed to the compressive strength properties and have improved the compressive strength by nearly 3% in FRCs. PM0.25% has achieved the 56 day strength earlier and gained higher strength than normal concrete in 56 days. Most of FRCs strength is comparable to that of reference at later ages. With this particular fibre, the strength gain reaches the reference at 18 days and starts to improve with time. After 56 days, the compressive strength curve seems to get closer to the reference concrete and continues a parallel trend with the reference concrete. To get the graph, three mixes with 0.25% monofilament fibre have been tested and results were averaged and plotted.

Figure 1, shows the curves derived from the 4 point bending test and an analysis and discussion of the results is being presented. These diagrams are plotted for the beams with mixes CF, PM0.25% and PF1%.

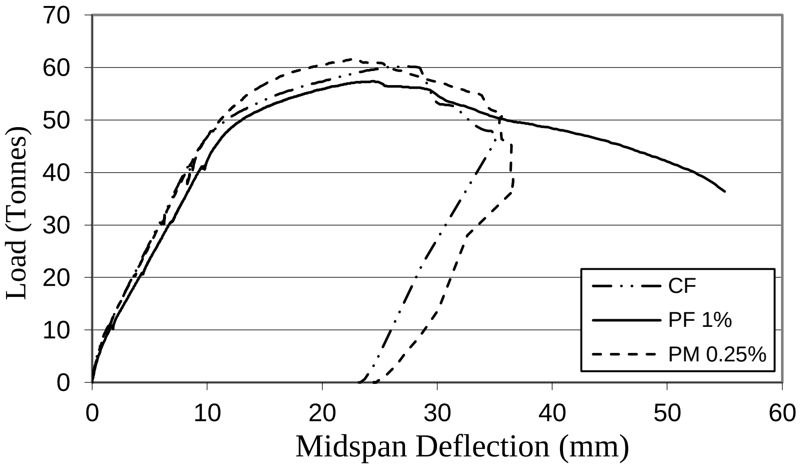

Figure 1: Load deflection curve.

The compressive strength of each mix together with the maximum load and deflections are used in Table 2, to calculate the ductility factor of the reinforced beam. As it is also observed from the load-deflection curve, the beam containing 1% fibre shows a much higher ductility than that of conventional concrete. Fibres do not significantly affect the uncracked portion of the curve but greatly influence the post peak behaviour. The uncracked portion of the curve is the part which the slope of the curve does not change and at a specific load this slope changes which shows the stiffness change in the beam. Post peak behaviour starts at the point where the steel bars yield and plastic bending moment occurs.

Table 2: Ductility factor calculation

Mix ID	Compressive Strength (MPa)	Maximum Load (KN)	δ_y (mm)	δ_{max} (mm)	Ductility Factor
CF	80.0	87.5	14.0	34.9	3.81
PM 0.25%	76.5	87.3	9.2	36.6	3.96
PF1%	71.8	86.9	10.3	62.8	6.09

4. CONCLUSION

It can be observed from the results that, adding 1% fibrillated fibre enhanced the ductility factor of the reinforced beam by 160% while keeping the ultimate load approximately the same. Using 0.25% PP monofilament fibre in the reinforced concrete mix improves the ductility by about 104%. Moreover, it can be concluded that the post peak behaviour observed in the beam containing 1% PP fibre is enhanced comparing to the reference beam and beam containing 0.25% PP fibre. From the tests conducted in this project, it can be understood that using PP fibres in the structural element do not affect the behaviour of the beam before the peak load but greatly can improve the behaviour of the concrete beam thereafter. Finally, where PP fibre is used especially in higher percentages, the stiffness has decreased slightly.

5. ACKNOWLEDGMENTS

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