23rd Australasian Conference on the Mechanics of Structures and Materials

2014

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Publication details

Ghosni, N, Samali, B & Valipour 2014, 'Flexural behaviour of high strength concrete composite incorporating long hooked-end steel fibres' in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. I, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 327-332. ISBN: 9780994152008.

FLEXURAL BEHAVIOUR OF HIGH STRENGTH CONCRETE COMPOSITE INCORPORATING LONG HOOKED-END STEEL FIBRES

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ABSTRACT

Herein, the flexural behaviour of high strength cementitious composites containing fly ash (FA) and manufactured sand is investigated. Long hooked-end steel fibres have been added to the mix design and compressive strength and flexural strength tests have been performed at the age of 7, 28 and 56 days and 14, 28 and 56 days respectively. The results of this engineered cementitious material have then been compared to plain concrete and also a reference cementitious composite containing Fly ash (FA). The flexural test is conducted under a 4 point bend test following fibre reinforced concrete relevant standards. Results indicate that adding the long hooked-end steel fibre to the cementitious mix demonstrates strain hardening and multiple cracking phenomenons. This characteristic categorizes the mix as high flexural strength cementitious composite demonstrating acceptable post peak behaviour. Concrete's ability to withstand compressive stresses is significantly higher than its ability to hold tensile strength, thus the addition of steel bars into concrete are used to reinforce the concrete in its tensile zone. Due to the compressive strength results gathered in this research, on steel fibre modified cementisius composite, which also reveal comparable measures to the control concrete and reference cementitious composite, the product of this research can be used as a multipurpose high strength concrete composite.

KEYWORDS

Hooked steel fibre, fibre reinforced concrete (FRC), flexural behaviour, ductility.

INTRODUCTION

Designs to improve structures under dynamic loading and earthquakes have always been of attention. Earthquakes such as an 8.8 magnitude earthquake in Chile in 2010, a 7.5 magnitude earthquake Papua New Guinea's eastern coast in 2014, caused huge human casualties. Due to heavy loads applied to a structure under seismic action, generally the reinforcement in concrete structures are very congested which makes not only the construction procedure more complicated but also there is always a chance of not proper concrete vibration which causes weaker structural performance. As a matter of fact, the compressive strength of the concrete is incomparably higher than that of its tensile strength. Because of this deficiency, steel bars are used to reinforce the concrete structure in tensile zones. The stress-strain relationship for concrete is non-linear and the material does not generally obey hook's law, therefore an elastic limit cannot be identified. This phenomenon results in sudden failure of the concrete and categorises it as a brittle material. If the ductility of concrete material can be improved to a certain level, the reinforcement steel bars can ultimately be eliminated or at least reduced in concrete structures which results in savings of money, time, energy and effort.

In order to control concrete failure and weak points, FRC has been introduced to construction world around 1900 and its theoretical concepts have been developed since 1960's (Mindess 2007). Concrete matrix when loaded, starts with the crack propagation which may occur at the aggregate-paste interface, also, the position of crack initiation depends on the bonds and the local stress positions(Moir 2003). Fibres are known to control these cracks by bridging effect.

Ductility of a material can be defined as the ability to absorb the inelastic energy without losing its load bearing capacity. Higher inelastic energy absorption in a system means higher ductility. At crack location, as the tensile strain increases, fibre crossing becomes more and more activated as the crack increases. Pantazopoulouet et.al. (Pantazopoulou and Zanganeh 2001) claim that evidently, fibres contribute to tensile resistance due to the post peak ductile behaviour before failure but addition of fibre prevents particle movement in matrix which lowers the Poison's ratio regardless of the fibre type. The reason flexural test is very famous is that it simulates the real condition in a more practical and simpler way than that of the tension test (Gopalaratnam and Gettu 1995).

The strain hardening or softening behaviour can be mainly described by the amount and type of fibre used. For instance, if Polyvynil Alcohole (PVA) Fibres are incorporated, a strain softening can be observed (A. Noushini, K. Vessalas et al. 2013). Whereas in case of steel fibre, strain hardening is mostly detected where multi cracks can be observed. Presence of fibres in the mix causes an excessive residual strength after the initiation of the cracks. In the post peak region, fibres tend to help with the ductility of the concrete elements transferring stress across the cracked section and reducing the crack widths.

Some other approaches have been researched to strengthen the structural performance of concrete for seismic loading such as using of FRP (Shrestha, Smith et al. 2008) or changing the design criteria of seismic prone structures. Using of FRC has advantages over most of the other procedures. These can be the ease of construction and reduction of labour costs, moreover, in the long run there is always a place for proper rehabilitation and strengthening for FRC structures due to the fact that even after failure, the structure generally will not collapse and fall apart and the elements are attached together.

EXPERIMENTAL PROGRAM

Material and Methodology

Different concrete mix designs containing Hooked End Steel (HES) fibres based on characteristics reviews, with diverse percentage volumes were prepared and tested to instigate this project (Table 1 and Table 2). The tests conducted in this project are static mechanical properties tests to evaluate the behaviour of each mix. These mixes include replacement of 30% fly ash with cement. In order to have a reference for our final mixes, 100% plain concrete with no fly ash was also prepared to compare the performance of the mix designs.

Shrinkage limited PC, with a typical fineness index from 310 to 370 m^2/kg is used in this project. Shrinkage limited Portland cement (PC) is a special purpose PC manufactured from specifically prepared clinker and gypsum and often contains up to 5% by mass of mineral additions in accordance with Australian Standard (AS) 3972-2010 (StandardsAustralia 2010) Portland and blended cements specification .

Table 1. Properties of PP fibres used

Technical Data	HESF
Nominal Diameter (mm)	0.9
Length (mm)	60
Aspect ratio	65

Table 2. Mix design and poroportioning

Technical Data	PC (kg/m^3)	FA (kg/m^3)	Fine Aggregate (kg/m^3)	10mm Coarse Aggregate (kg/m^3)	20mm Coarse Aggregate (kg/m^3)	Fibre (%)	Water/ Cement
CF	301.0	129	635.0	390.0	700.0	0.00%	0.35
0.25% HESF	301.0	129	635.0	390.0	700.0	0.25%	0.35
0.5% HESF	301.0	129	635.0	390.0	700.0	0.50%	0.35
1% HESF	301.0	129	635.0	390.0	700.0	1.00%	0.35

Testing

Compressive strength testing is carried out after 7, 28 and 56 days of ageing. A universal testing machine applying axial loads on 100×200 mm cylinders was used. Flexural strength testing (4-point bending test) – after 14 and 28 and 56 days of ageing for computing the modulus of rupture (MOR) was carried out. A universal testing machine was used to test 100×100×350 mm prisms under flexure. Linear variable differential transformer (LVDT)s were installed to monitor the deflection of the samples under loading condition. In this project, for the flexural strength testing, AS 1012.11— (1985) set up has been used to determine the flexural behaviour of the concrete specimens. ASTM C 1609 (ASTM 2010) has also been used to help calculate and measure specific characteristics of concrete under flexure.

In this test the loading rate was applied constantly for all mixes according to ASTM C1609 in order to avoid any misleading values between the reference concrete and modified mix specimens. According to mentioned standard, for beam size of 100×100×350mm for net deflection up to L/900 (0.38 mm in this case) the loading rate is 0.025 to 0.075 mm/min and for deflections beyond the mentioned value, the loading rate should be 0.05 to 0.2 mm/min. Depth and width of each specimen were measured in 3 sections to work out the average depth and width of the prism length was also measured. Some fluctuations on the deflection measurements were observed during the tests which are discussed in literature and proved not to have a significant influence on the values (El-Shakra and Gopalaratnam 1993).

RESULTS AND DISCUSSIONS

Compressive Strength

Results of compressive tests are illustrated in Table 3. 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 fibre has reached the highest compressive strength in general comparing to the control concrete. At this percentage, fibres have contributed to the compressive strength properties and have improved the compressive strength by nearly 109%. Comparing FRCs strength to that of reference at later ages, using 0.25% of fibre in concrete has gained the highest strength in both 28 and 56 days comparing to control concrete and also other fibre percentage. The amount of strength increase comparing to control concrete at 28 and 56days are 133% and 125.5% respectively.

Table 3. Compressive Strength

Technical Data	7-days	28-days	56-days
CF	46.0	57.5	70.3
0.25% HESF	50.2	67.5	88.2
0.5% HESF	48.2	64.6	77.7
1% HESF	52.3	66.7	75.0

Flexural Strength

Table 4, shows the results of the MOR test after 14, 28 and 56 days. By comparing the results of FRCs with their reference concrete (CF), it is observed that by adding fibre to the mixes, the modulus of rupture is positively affected and a higher value can be achieved. FRCs results show that 0.25% of fibres improve the MOR and by increasing the percentage of the fibre in the mix, this value increases.

Table 4. Flexural Strength

Technical Data	14-days	28-days	56-days
CF	5.0	5.6	7.1
0.25% HESF	5.1	6.0	7.2
0.5% HESF	5.4	6.7	7.7
1% HESF	6.9	8.5	11.3

In ASTM, the available standard regarding FRC, is used bellow to calculate properties and behaviour of unconventional concrete. According to ASTM C1609 (ASTM 2010), assuming the linear elastic behaviour up to the first peak, the first peak deflection of the FRC in 4-point bending testing can be calculated from below equation:

$$\delta_1 = \frac{23P_1L^3}{1296EI}\left[1+\frac{216d^2(1+v)}{115L^2}\right] \tag{1}$$

Where:"P1" is the first peak load, "L" is the span length, "E" is the estimated modulus of elasticity in MPa, "I" is the cross sectional moment of inertia, "d" is the average depth of the specimen at fracture and "v" is the poison's ratio. ASTM publication on concrete testing (James Pielert 2006) permits using this equation for the normal concrete as well, therefore in order to be able to compare the data calculations and plotting for the conventional concrete can also been tried to evaluate the behaviour of the FRC, FRPMC and conventional concrete.

First peak point on the load deflection curve is where the slope is zero and the load is at the local maximum. Using this point and using the formula presented by ASTM C1609, the first peak strength can be calculated (There are small fluctuations in the curve which is due to noise or mechanical vibration which according to the standard is natural but needs to be monitored and not confused with the actual values):

$$f = \frac{PL}{bd^2} \tag{2}$$

In this standard other characteristics have been required to be calculated to evaluate the behaviour of FRC. The residual load values corresponding to net deflection of 1/600 and 1/150 of span lengths help finding the residual strength values and also corresponding toughness. Below figure is extracted from the standard which shows the readings from the load deflection curves.

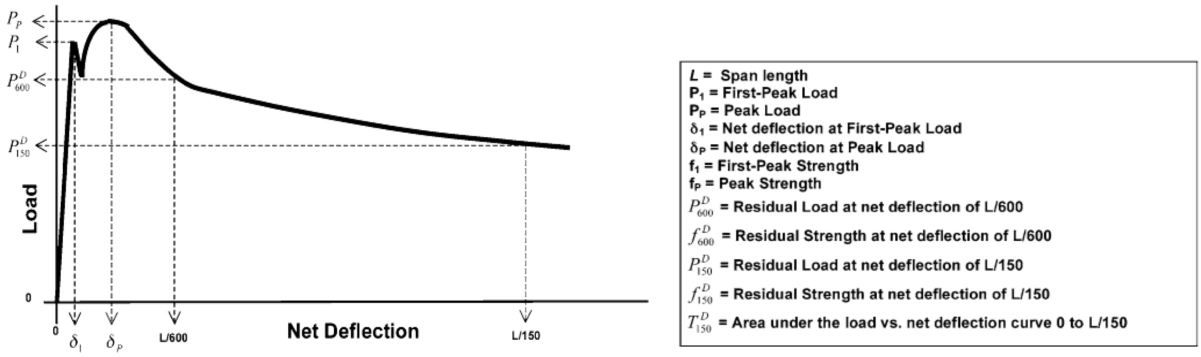

Figure 1. Example of parameter calculations for first-peak load equal to peak load (ASTM 2010)

For FRCs these values are calculated. The total area under the load deflection curve up to the net deflection of 1/150 of the span length is the toughness which will be presented in Joules. Using the first peak strength, the equivalent flexural strength to the toughness is calculated from below equation:

$$R^D_{T,150} = \frac{150T^D_{150}}{f_1.b.d^2} \times 100\% \tag{3}$$

As test prisms are 100mm $\times$ 100mm $\times$ 350mm with span length of 300mm, therefore, L / 150 = 2mm and L / 600 = 0.5mm. Readings from the graphs are respectful of these values. For specimens with lower percentage of fibres, weaker post peak behaviour has been observed, whereas in larger percentages, FRC show satisfactory behaviour after peak load. This behaviour is more pronounced in mixes containing higher fibre volume percentages. These calculated results are used and presented in next section to evaluate the flexural toughness. Calculations are derived from those mixes with acceptable post peak behaviour. Due to very weak post peak behaviour of the conventional concrete, none of the calculations in this standard can be applicable to them with the data captured in this project. The conventional concrete did not reach the L/150 and L/600 deflections necessary to measure and calculate the related residual strength of the concrete.

It is reported that by adding fibre to the mix the matrix toughness increases [14]. The toughness results of this project are also in harmony with the reports of literature. With regards to ASTM C1609, FRC results are calculated taking into account six test samples from two sets of mixes. The area under the full curve up to L/150 has been calculated. This value indicates the energy absorbed up to the net deflection of 2 mm.

Table 5. ASTM calculations for 28day toughness and residual strength

Technical Data	P_1 (kN)	P_2 (kN)	δ_1 (mm)	δ_2 (mm)	P^D_{150} (kN)	P^D_{600} (kN)	f^D_{150} (MPa)	f^D_{600} (MPa)	T_{150} (N.m)
0.25% HESF	18.6	20.9	0.2	1.1	15.2	11.0	4.6	3.3	23.0
0.5% HESF	20.5	22.0	0.2	1.4	17.6	15.5	5.3	4.6	52.9
1% HESF	25.7	32.2	0.4	1.3	27.9	25.4	8.4	7.6	203.1

Results indicate that the ultimate strength and post peak response of the FRC increases by incorporating higher amount of fibre in the matrix. Where 1% of steel fibre is incorporated the toughness has been dramatically increased even compared to 0.5% fibre usage. There is an optimum amount of fibre usage for the mix design which can be investigated in future works.

CONCLUSIONS

The results of this research show that by adding hooked end steel fibres as an additive to the mixes the mechanical properties of concrete improves. By adding these fibres in to the mix promising results can be gained in different percentages. According to the achieved results some general comments can be made. Incorporating hooked end steel fibre with diverse percentage can help improve both compressive strength and flexural strength of the concrete mix. Where higher percentages of fibre are used, especially at 1%, considerable post peak behaviour is observed. Use of hooked end steel fibres in the concrete matrix, helps improve the energy absorption capacity and flexural toughness of concrete composite.

ACKNOWLEDGMENTS

The authors would very much like to record their appreciation to Mr. Rami Haddad, Civil Engineering Laboratories Manager at the University Of Technology Sydney (UTS), for his valuable advice and support from the commencement of this project and for his unfailing assistance and support in this research work.

REFERENCES

A. Noushini, K. Vessalas, et al. (2013). "Effect of polyvinyl alcohol fibre and fly ash on flexural tensile properties of concrete." *From Materials to Structures: Advancement Through Innovation - Proceedings of the 22nd Australasian Conference on the Mechanics of Structures and Materials,* : 1165-1170.

ASTM, I. (2010). Standard test method for Flexural Performance of Fibre reinforced Concrete (Using Beam with THird point Loading). *United States*.

El-Shakra, Z. M. and V. S. Gopalaratnam (1993). "Deflection measurements and toughness evaluations for FRC." *Cement and Concrete Research* 23(6): 1455-1466.

Gopalaratnam, V. S. and R. Gettu (1995). "On the characterization of flexural toughness in fiber reinforced concretes." *Cement and Concrete Composites* 17(3): 239-254.

James Pielert , J. L. (2006). Significance of Tests and Properties of Concrete and Concrete-Making Materials, *ASTM International*.

Mindess (2007). Thirty years of Fibre Reinforced Concrete research at the UWM British Colombia. P. Int, Sustainable construction materials and technologies: 259-268.

Moir, G. J., Newman (2003). Concrete Properties. *Advanced Concrete Technology Set*. Oxford, Butterworth-Heinemann: 3-45.

Pantazopoulou, S. J. and M. Zanganeh (2001). "Triaxial Tests of Fiber-Reinforced Concrete." *Journal of Materials in Civil Engineering* 13(5): 340-348.

Shrestha, R., S. T. Smith, et al. (2008). "Effectiveness of strengthening RC beam-column connections in shear with vertical FRP strips " *Fourth International Conference on FRP Composites in Civil Engineering (CICE2008).*

StandardsAustralia (2010). General purpose and blended cements. AS 3972-2010.