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Behaviour of fibre reinforced concrete slabs

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ABSTRACT: This paper presents a comparison of the properties of concrete slabs when two types of fibres are added. One specimen had no fibres and acted as a control specimen. The remaining four specimens had steel and polypropylene fibres added in the volumetric ratio of 0.5% and 1.0%. The dimensions of the slab specimens were 820×820×80 mm and were supported by four rollers at their edges. A displacement controlled point load was applied at the centre of the slabs. The ductilities of the tested slabs were calculated and compared so as their load carrying capacities. Results of the experimental programme were compared with theoretical predictions. Based on the results of the experimental programme, it can be concluded that the addition of 1% by volume steel fibres had the best effect on the ductility of the slabs.

1 INTRODUCTION

This study focuses on comparing the behaviour of steel fibre reinforced concrete slabs and polypropylene fibre reinforced concrete slabs. Comparison of the experimental results with theoretical results is also included in this study.

Fibre reinforced concrete decreases efficiently the brittleness of concrete, and it improves its characteristics. There are two main types of fibres: steel fibres and polypropylene fibres which have been studied in recent years. The ductility of concrete is an important property that can be increased by using steel fibre reinforcement. Generally, the cost of construction can be reduced by mixing steel fibre into plain concrete. Therefore increasing the toughness of concrete and its resistance to impact.

The objective of this study is to determine the flexural strength, load-deflection curve and energy absorption of concrete slabs by comparing of the various percentages of steel and polypropylene fibres. The test results were compared with the theoretical values and are presented herein.

2 REVIEW OF LITERATURE

Song et al. (2005) performed experiments that added fibres into high-strength concrete. Steel fibre reinforced concrete was mixed in moulds to cast 12 cylinders of 150×300 mm. Twelve other samples were cast using high strength concrete. Impact resistance tests were conducted and the main conclusion from their work was that the impact resistance of high strength fibre reinforced concrete (HSFRC) have a significant improvement compared with HSC.

Pigeon and Cantin (1998) performed a test to investigate the flexural properties of steel fibre-reinforced concretes at low temperatures. The experiment was performed at -10°C and at -30°C. Using two types of cement (normal Portland cement and silica fume cement), the water binder ratio (0.45, 0.35 and 0.30), and two types of different fibres and the fibre dosage (40 kg/m^3 and 60 kg/m^3). It was quite a small effect for the fibre geometry in these experiments. The first conclusion was that when temperature decreases the toughness of steel fibre reinforced concrete under flexural loading increases. It is the consequences present that the toughness of SFRC under flexural loading increases with a decrease in temperature. It has a connection with the raise in the forces of the based body at low temperatures (because of the freezing of water in the capillary pores) which raises the energy needed for fibre fall. The raise in forces was remarked both for usual concretes (with a water/binder ratios of 0.45) and high performance concretes (with a water/ binder ratio of 0.30), and for two very different types of fibre at two fibre dosages (40 and 60 kg/m^3).

Song and Hwang (2004) investigated the mechanical properties of high-strength steel fibre-reinforced concrete. In compressive strength test, 15 standard test cylinders were used (150×300 mm). Splitting tensile test was also performed using 15 beams (150×150×530 mm). The different volumes of the steel fibre were used in the test (0, 0.5, 1, 1.5 and

2%). This study has shown that the compressive strength of HSC improved when the fibres were added in the concrete and the maximum strength happened when 1.5% fibres was added in the concrete. The splitting tensile strength also has improvement (98.3% improvement at 2% fibre)

Gunneswara and Seshu (2003) studied the behaviour of the torsion of steel fibre reinforced concrete members. The volume fraction of the fibre varied from 0% to 1.2% at an equal interval of 0.3% and the strength of the concrete was 20, 30, 40, 50 MPa. 20 beams were cast for testing (100×200×2000 mm) under pure torsion. The beams were supported by two rigid supports at the each end to simulate a simply supported beam. The twist arms were placed at either supports of the beam. Loads were applied on the two twist arms. For each load increment the corresponding twist per unit length was measured until the specimen failed. All the beams failed with a single potential crack with the volume fraction 0.3 and 0.6%. The beams failed suddenly and violently and these beams got separated into two pieces. But the fibrous beams with volume fraction of fibres 0.9 and 1.2% were not separated into two pieces showing a better ductility. According to the comparison, the ultimate torsional strength, torsional toughness and torsional stiffness increased due to the addition of steel fibres. The improvement of torsional toughness has higher improvement in higher grades of concrete than low grade of concrete.

Nataraja *et al.* (2005) tested steel fibre reinforced concrete (SFRC) mixes with fibre volumes of 0.5%, 1.0% and 1.5% and 0% (plain concrete as a reference) and concrete strengths of 30MPa and 50MPa, in order to develop and validate a mix proportioning method for SFRC mixes, and to determine the impact resistance of steel fibre reinforced concrete. Nataraja *et al.* (2005) cast six cubes (150×150×150 mm) and six discs (150 mm diam×64 mm thick) for each of the eight mixes, giving a total number of 96 samples for all of the mixes. The steel fibres that were used were 40 mm long, 1 mm diameter round crimped steel fibres with ultimate tensile strength of 1010 MPa. The aspect ratio of the fibres used was 40. An initial mix design was prepared with a water cement ratio of 0.5, from which two other mixes were designed using the same slump of the initial mix. Three tests were then undertaken with the eight mixes, those being a workability test, an ultrasonic pulse velocity test and an impact test. The workability test involved a slump test and a Vee-Bee test. The results of these tests showed that workability decreases significantly with the addition of fibres, although Nataraja *et al.* (2005) also notes that a slump test is not a good measure of workability for SFRC and that a needle vibrator will assist in placement. The ultrasonic pulse velocity test measures the uniformity of the concrete and therefore the quality of the concrete. The test indicated that the samples were of good quality and showed that the strength of the concrete increases with an increase in fibre volume, albeit marginally, as concluded by Nataraja *et al.* (2005). The impact test measured the impact resistance of the samples. A weight of 4.5 kg was dropped from a height of 0.45 m onto a steel ball of 64 mm diameter, which rested upon the centre of a concrete disc sample. The relative performance of the samples was measured, by comparing the number of required blows to cause visible cracks in the top surface of the disc and the number of blows required to cause the specimen to fail. The results of the test indicated that while the plain concrete sample failed in a brittle manner with only a few blows to crack the samples and cause failure, the SFRC samples had in the order of 40% to 60% increase in crack resistance compared to the plain concrete. SFRC also had up to 25 times the impact resistance of plain concrete. The conclusion of the study was that post crack resistance in SFRC is 50% higher than that of plain concrete and that the addition of steel fibre to concrete significantly improves impact resistance.

Choi and Li (2003) compared the failure mechanisms of ring type steel fibre reinforcement with straight hooked-end steel fibres. Flexural tests under 3-point loading were carried out with samples of varying ring diameter (20, 30, 40, 50 and 60 mm) and fibre diameter (0.4, 0.5, 0.8 and 1.2 mm) for the ring steel fibre reinforced concrete (RSFRC) and fibre length (45 and 60 mm) at 0.6 mm fibre thickness for the straight hooked-end steel fibre reinforced concrete (SHSFRC). Concrete strength of 33.9 MPa at 28 days was used. Beam samples (350×100×100 mm) were loaded at a rate of 0.01mm/min until the midspan deflection reached 2.0 mm. The results of the test showed that the ring type fibres failed by one of three modes: tensile fibre rupture after yielding, concrete fracture (in a conical shape) and separation of the fibre and matrix. The SHSFRC failed by one mechanism only, the pull out of fibres prior to yielding. Choi and Li (2003) observed from the results that the ring diameter of the steel fibre and fibre volume both affect the flexural toughness of RSFRC and that there is an optimum ring diameter for any given concrete mixture. Flexural toughness appeared to increase with decreasing ring diameter. The research also showed that RSFRC performed better (45% overall) than conventional SHSRFC.

Khaloo and Afshari (2005) performed an experimental programme in order to determine the flexural behaviour of steel fibre reinforced concrete (SFRC) slabs. Fourteen concrete mixtures with four different fibre contents, two different fibre lengths and two concrete strengths were designed in order to compare and analyse the results. The strength of the concrete was 30 and 45 MPa and the fibre volumetric percentage was 0, 0.5, 1 and 1.5. The results of the experiments of Khaloo and Afshani (2005) have

shown that the plain slabs failed suddenly at cracking load without any appreciable deflection warning but the SFRC slabs with fibres failed gradually after the concrete slabs cracked. The conclusions drawn from the experimental programme are: the ultimate flexural strength of SFRC slabs does not increase significantly when the fibres are added to the concrete but the energy absorption capacity of slabs increased remarkably. Secondly, the resisting load after cracking was relatively low in the low volume fibre. The range of volume from 0.75-1.75 was recommended. Thirdly, a design method was set up according to the comparison between experimental value and theoretical value.

It is known that the concrete is a brittle material. Research on how to improve the performance of the concrete continues since the last four decades. In order to reduce its brittleness and improve its mechanical properties, fibres are added to reinforced concrete. Some experiments have already been done and most results have shown that the performance of the concrete can be improved by adding the extra fibres but the magnitude of the effect and optimised content of the fibre in concrete still need further study. This paper is a step in this direction.

3 EXPERIMENTAL PROGRAMME

Five slabs were cast and tested. The dimensions of the slabs were 820×820×80 mm. Wooden forms were used to cast the slabs. One of the slabs was cast without fibres, two slabs had steel fibres at the percentages of 0.5 and 1.0 by volume and the remaining two slabs had polypropylene fibres with the same percentages of 0.5 and 1.0 by volume. The first slab acted as a reference slab to the other four slabs. All slabs were made without reinforcement. Table 1 shows the details of the tested specimens. As most literature indicate that the optimum percentage of fibres is 1, this study has limited the maximum fibre percentage to 1. The steel fibres were hooked at both ends and had a length of 35 mm and a diameter of 0.55 mm. The polypropylene fibres had a length of 19 mm.

Table 1 Slabs' details.

Slab No	Dimensions mm^3	Fibre Type	Percentage by Volume
R	820×820×80	None	0.0
0.5PP		Polypropylene	0.5
1.0PP			1.0
0.5SF		Steel	0.5
1.0SF			1.0

The concrete was purchased from a local supplier. The reference specimen was first poured to the formwork. A predetermined volume of concrete was poured to the mixer in the lab and a predetermined volume of fibres was added. The mix was mixed thoroughly and the second specimen was poured. The pouring technique was repeated for the three remaining three specimens.

Small and large cylinders as well as small beams were cast for each of the five different mixes. The small cylinders (100×200 mm) were used to test the compressive strength of the concrete mix, the large cylinders (150×150 mm) were used to test the splitting strength of the concrete mix and the small beams were used to test the flexural strength of the concrete mix. All tests were conducted based on the relevant Australian Standard.

After casting, all the specimens (slabs, cylinders and beams) were cured by covering them with wet Hessian and plastic sheets for 14 days. After that they were left to cure at room temperature in the labs. Four triangle steel slices were installed at the four corners of each slab formwork. Before casting the concrete, the formwork was wiped with the lubricant to allow ease of removal.

Compressive strength test, indirect tensile test and flexural strength test were carried on the concrete mixes. All these tests were undertaken using the relevant Australian Standards.

The slabs were removed from the curing environment and fixed on the testing machine (see Fig. 1) and four corners of the slabs were seated on the roller points. Two LVDTs were also connected to measure the deflections. A laser LVDT was used to measure the deflection of the middle of the slabs. A point load was applied by actuator and a 75×75×50 mm steel block was placed at the slab centre. A computer scanned and stored the applied load and the deflection at every three seconds.

Figure 1 Slab testing.

For the plain slab, the loading rate was one millimetre per 60 seconds. Once the maximum load was achieved during the test, the applied load was then decreased rapidly and then the slab collapsed.

For the remaining slabs (0.5PP, 0.5SF, 1.0PP and 1.0SF), the loading rate was 60 seconds per millimetre before the slabs achieved the maximum load and

then 30 seconds per millimetre was used until the slabs failed. Once the maximum load was reached during the test, the applied load decreased quickly but the ultimate deflection increased.

4 EXPERIMENTAL RESULTS

4.1 *Concrete Results*

The results of the compressive strength, indirect tensile strength and flexural strength of the different batches are shown in the Table 2.

Table 2 Results of testing concrete.

Batch	Compressive strength	Tensile strength	Flexural strength
	MPa	MPa	MPa
R	11.3	2.6	4.1
0.5PP	11.5	2.5	3.6
1.0PP	12.4	2.4	3.7
0.5SF	13.9	2.5	4.1
1.0SF	14.2	3.4	4.9

4.2 *Slabs Results*

The load deflection curve for Slab R is shown in Figure 2 and Load-deflection curves of the tested slabs 0.5PP, 1.0PP, 0.5SF and 1.0SF are shown in Figures 3, 4, 5 and 6, respectively.

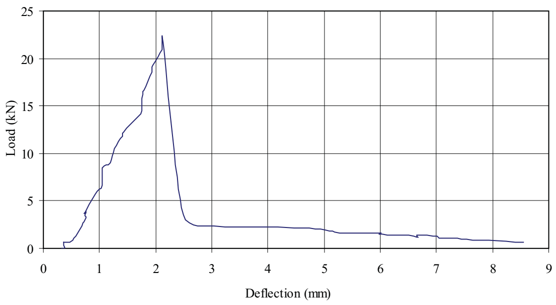

Figure 2 Load – deflection curve of plain slab (Slab R).

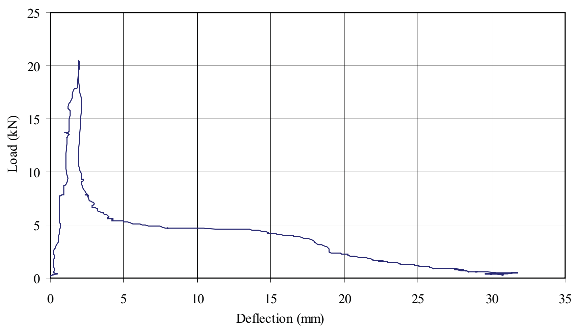

Figure 3 Load – Deflection curve of Slab 0.5 PP.

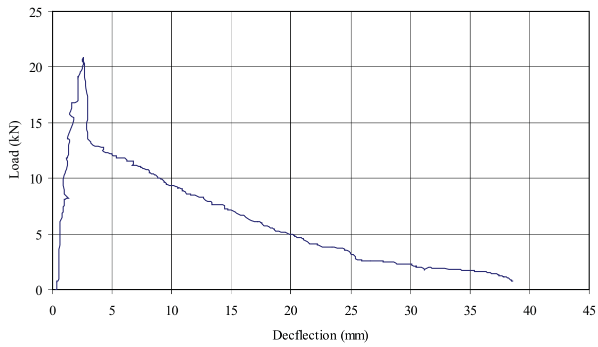

Figure 4 Load – deflection curve of Slab 1.0PP.

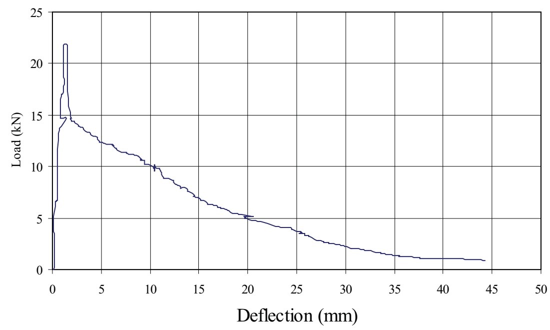

Figure 5 Load – deflection curve of Slab 0.5SF.

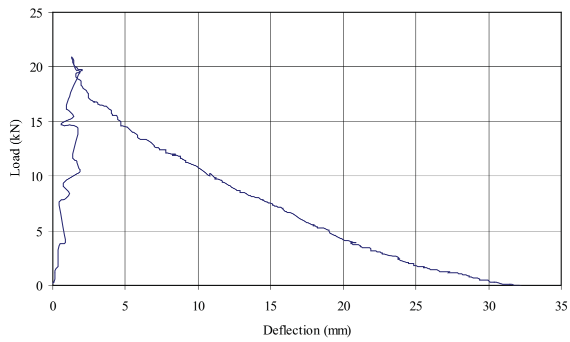

Figure 6 Load-deflection curve of Slab 1.0SF.

5 ANALYSIS OF RESULTS

5.1 *Ultimate Strength of Slabs and Energy Absorption Characteristics*

The presence of steel fibres and polypropylene fibres in concrete did not significantly influence the ultimate strength of the slabs and the deflection at the maximum load. Small variation in the ultimate strength was due to changes in the compressive strength of the concrete caused by the addition of fibres. The fibres did not significantly influence the flexural characteristics of the slabs before cracking. But the ultimate deflection has significantly increased when steel fibres and polypropylene fibres were used in the concrete slabs. As shown in Table 3, Slab 0.5PP showed higher ultimate deflection than Slab 1.0PP.

Table 3 clearly shows that the slab that included steel fibres had higher ultimate deflection than the concrete slab that included polypropylene fibres at content 0.5% but the slab that included steel fibres had lower ultimate deflection than the concrete slab that included polypropylene fibres at 1.0% content.

Figure 7 shows the load-deflection curves for Slabs 0.5PP and 1.0PP. Similarly Figure 8 shows the load-deflection curves for Slabs 0.5SF and 1.0SF.

Table 3 Test result of slabs.

Slab	Ultimate load	Deflection at max load	Ultimate deflection
	kN	mm	mm
R	22.29	2.11	2.11
0.5PP	21.24	1.95	30.76
1.0PP	20.90	2.56	38.60
0.5SF	21.90	1.19	44.20
1.0SF	20.90	1.33	32.40

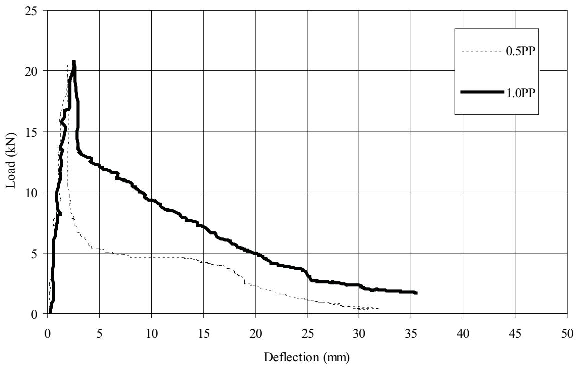

Figure 7 Load-deflection curves for Slabs 0.5PP and 1.0PP.

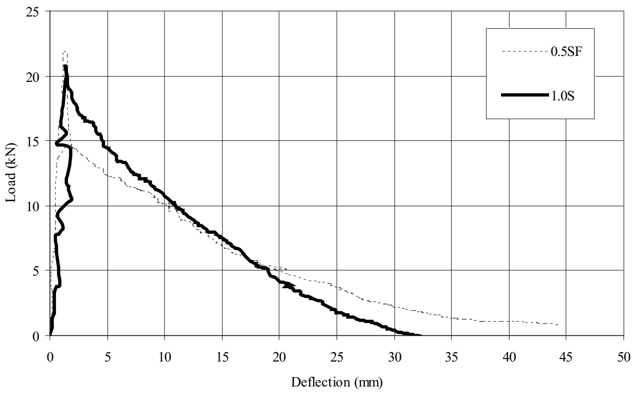

Figure 8 Load-deflection curves for Slabs 0.5SF and 1.0SF.

It is obvious that the concrete slab that included steel fibres had higher energy absorption capacity than the concrete slab that included polypropylene fibres at both 0.5% and 1.0% content in slabs. Also, Slab 1.0SF had higher energy absorption capacity than Slab 0.5SF. Similar results were observed for the polypropylene slabs. Slab 1.0PP had a higher energy absorption capacity than Slab 0.5PP.

As shown in Table 4 the energy absorption at the maximum load (area under the load-deflection curves), is almost similar for all tested slabs. However, added steel fibres and polypropylene fibres both have significant effects on the total energy absorption of the slabs.

Table 5 shows the ductility of the tested slabs. When compared to the slabs without fibres, all slabs had more ductility than the plain concrete slab.

Table 4 Comparison of energy absorption.

Slab	Energy absorption at max load	Total energy absorption	Improvement at max load	Improvement of total energy absorption
	J	J	%	%
R	18.1	18.1	0	0
0.5PP	19.7	116.6	8.8%	544%
1.0PP	28.6	232.9	58%	1186%
0.5SF	20.2	249.1	11.6%	1276%
1.0SF	20.1	278.1	11%	1436%

Table 5 Ductility results.

Slab	Ductility
R	4.0474
0.5PP	15.7744
1.0PP	15.1969
0.5SF	29.4867
0.5SF	24.1791

5.2 *Comparison Between Experimental Results and Theory*

Khaloo and Afshari (2005) have shown a theoretical basis for the analysis of slabs as shown below:

For $0 \le \xi \le 1$:

$$F = 3.718 f'_c z\left[0.6z + (h-z)\frac{6-8\xi+3\xi^2}{12-12\xi+4\xi^2}\right] \quad (1)$$

$$w = \frac{\xi l_f (b-a)}{8(h-z)} \quad (2)$$

For $\xi > 1$:

$$F = 3.718 f'_c z\left(0.6z + \frac{h-z}{4\xi}\right) \quad (3)$$

$$w = \frac{\xi l_f (b-a)}{8(h-z)} \quad (4)$$

Where: F is the applied load, a is the length of a the applied load, b is the distance between rollers, c is the overhanging length of slab, h is the thickness of the slab, z is the compressive zone depth, l_f is the length of fibres, and ξ is the crack opening parameter. The value of ξ was arbitrarily changed in order

to determine the complete load-deflection curve for 0.5SF and 1.0SF. These curves are shown in Figures 9 and 10.

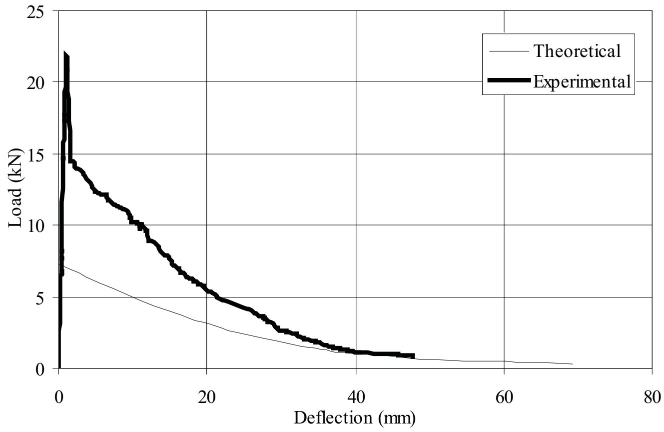

Figure 9 Experimental and theoretical load-deflection curves for Slab 0.5SF.

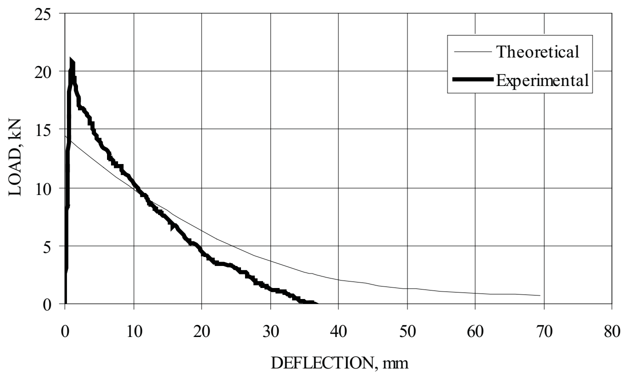

Figure 10 Experimental and theoretical load-deflection curves for Slab 1.0SF

6 CONCLUSIONS

Based on the results of this, the following conclusions are drawn:

During the compressive strength test at 28 days, 1.0% steel fibre concrete slab had the highest compressive strength 14.2 MPa. Moreover the test results showed that the presence of steel and polypropylene fibres were both sufficient to increase the strength of the concrete, however the steel fibres had more effect.

The test results showed that the ultimate deflection has significant increase when steel and polypropylene fibres were added into the concrete slabs. Moreover slabs including steel fibre have higher ultimate deflection than the concrete slab that included polypropylene fibres at 0.5% content.

The final collapse takes longer than plain concrete slab when fibres were added in.

Adding steel and polypropylene fibres both had significant effects on the total energy absorption, and at the same time, more fibre content in concrete decreased the growth rate of total energy absorption. In addition, adding steel fibre has higher energy absorption capacity than polypropylene at both 0.5% and 1.0% content in slabs.

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