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EFFECTS OF STEEL FIBRES ON CONCRETE PROPERTIES AND FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE SLABS

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Abstract: Concrete is a material that is good in compression but weak in tension. Enhancing the tensile properties of concrete will lead to its greater application in construction. It was reported that improvement on the mechanical properties of reinforced concrete structure can be achieved by the inclusion of short fibres. The use of short steel fibres have been reported to increase the toughness, abrasion, impact resistances and allow for decrease in concrete slab thickness. This paper focuses on the study conducted in the laboratory on the effect of steel fibre on concrete properties and behaviour of steel fibre reinforced concrete slabs under flexure with different amount of tensile reinforcements. A number of concrete cubes and prisms with and without steel fibres, 0%, 0.5%, 1.0%, 1.5% and 2.0% together with four reinforced concrete slabs having different amount of tensile reinforcement were cast and tested to failure in flexure. The optimum dosage of steel fibre to be included in concrete slab was 1%. The reinforced concrete slabs manufactured consist of slab with tensile reinforcement bar of R-150 as control slab, slab with tensile reinforcement bar of R-300 and 1% dosage of steel fibres, slab with 1% dosage of steel fibres without tensile reinforcement, and one plain concrete slab without reinforcement. All the slabs cast having the overall dimensions of 100 x 500 x 1000 mm, and tested to failure under four point loading. Cube compressive strength, modified compressive strength, flexural strength, ultrasonic pulse velocity test and rebound hammer test were conducted. The behaviour of the reinforced concrete slabs was studied through their ultimate load, load-deflection characteristic upon loading, cracking history, and mode of failure. The experimental results show that the inclusion of steel fibres was found to improve the compressive strength, slightly lowered the UPV value but no significant effect on the rebound hammer compared to the control sample. It was also found that based on slab SB-R300-1SF the inclusion of steel fibres increased the ultimate load of the slab by 25%, reduce the tensile reinforcement by about 50%, improve the flexural stiffness and ductility of the slab when compared to the control slab, SC-R150.

Keywords: *Steel fibres, reinforced concrete, slab, flexural capacity*

1.0 Introduction

Reinforced concrete has become one of the most widely used materials in the construction of buildings, bridges, dams and other infrastructures. Although concrete is a versatile material and strong in compression but it is weak in tension. Thus, cracks or micro cracks may occur under the applied load during the service life of the structure. Normally in an industrial building, ground floor slab (non-suspended slab) functions to sustain dead or live loads from goods stored directly on the floor or the wheel of fork lift and transferring the load to the supporting soil (Tatnall and Kuitenbrouwer, 1992). Therefore, the design of most industrial floor slab needs to provide sufficient reinforcement to cater for the heavy static or dynamic loads. One of the methods that can be used to enhance the tensile properties of concrete is to introduce steel fibres into the concrete mix especially for the ground floor concrete slabs application. Previous studies have shown that the inclusion of short steel fibres in concrete was found to improve the tensile properties of concrete (Balendran *et. al*. (2002); Tanoli *et. al*. (2014)). The main purpose of adding steel fibres in concrete mix is to control cracks that may occur in concrete together with the enhancement on the tensile properties of the concrete. In addition, the use of steel fibres may reduce the amount of tensile reinforcement for ground slab and thus, will reduce the construction time as less tensile reinforcement bars to be fixed in the formwork. Besides, the fibres can control the cracking and improve other concrete properties as the fibres are randomly distributed throughout the concrete. Several past studies conducted had focused on the effect of fibres on the toughness and ultimate load-carrying capacity of steel fibre reinforced concrete slabs (Hrynyk and Vecchio, 2014; Ong *et. al.* (1999); Khaloo and Afshari (2005)). This paper looks into an investigation on the behaviour of steel fibre reinforced concrete slabs with different percentages of tensile reinforcement under flexure.

2.0 Materials and Methods

A total of 30 concrete cubes of 150 x 150 x 150 mm were cast with different dosage of fibres and tested to study the effect of different dosage of steel fibre on the compressive strength at the age of 7 and 28 days (BS 1881-116). In addition, five prisms of 150 x 150 mm cross section and 750 mm length were cast with different fibre dosage and tested at the age of 14 days. The details of the cubes and prisms tested are shown in Table 1. The dosages of steel fibre used were 0.5%, 1.0%, 1.5% and 2.0%. The concrete mixture was designed based on the DoE method to have compressive strength at the age of 28 days of 50MPa. The concrete was produced using maximum crushed coarse aggregate with the optimum size of 20 mm and water cement ratio of 0.40. The prisms were tested using ultrasonic pulse velocity test (BS 1881-203) and Rebound Hammer test (BS 1881-202) before being tested under flexure using four-point loading until failure (BS 1881-118). After the flexural test, the broken prisms were then tested to determine the compressive strength by using the portions of beam broken in flexure (equivalent cube method) (BS 1881-119). The results of the compressive strength test on cubes and the flexural test on prisms were analyzed to get the optimum dosage of fibres to be used to cast the reinforced concrete slab.

A total of four (4) reinforced concrete slabs designed based on BS 8110 with the dimension of 100 x 500 x 1000 mm were cast. One slab was reinforced with tensile reinforcement steel bar of R-150 acting as control sample, one slab was reinforced with tensile reinforcement bar of R-300 and mixed with 1% steel fibre, one slab without the tensile reinforcement was cast with 1% steel fibre only, and the last slab was a plain concrete without any reinforcement. The details of the slab are shown in Table 2. The slab was tested in flexure under four-point loading until failure and the schematic diagram of the test arrangement is shown in Figure 1.

Table 1: Details of concrete cubes and prisms

Sample	Sample Identification	Quantity	Fibre Dosage (%)	Weight of Fibre (kg)
Cubes	CB0.0SF	6	0.0	0.00
	CB0.5SF	6	0.5	0.79
	CB1.0SF	6	1.0	1.59
	CB1.5SF	6	1.5	2.38
	CB2.0SF	6	2.0	3.18
Prisms	P0.0SF	1	0.0	0.00
	P0.5SF	1	0.5	0.66
	P1.0SF	1	1.0	1.32
	P1.5SF	1	1.5	1.99
	P2.0SF	1	2.0	2.65

Table 2: Details of concrete slab

Slab Identification	Reinforcement	Diameter (mm)	Spacing and fibre percentage	Reinforcement Area (mm^2)
SC-R150	Steel bar	5	R5-150	262
SB-R300-1SF	Steel bar + Steel fibre	5	R5-300 1% steel fibre	142
SB-1SF	Steel fibre	-	1% steel fibre	-
SC-PLAIN	-	-	-	-

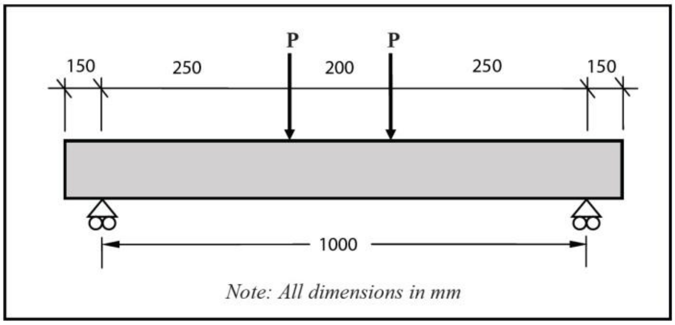

Figure 1: Schematic diagram of the reinforced concrete slab test setup

3.0 Results and Discussion

3.1 Cube Test

The results of the cube compressive strength of all concretes are shown in Table 3 and Figure 2. It can be seen that as the fibre dosage increase, the compressive strength will increase but started to decrease when the fibre dosage exceed the value of 1%. The highest average compressive strength at 7 days was 49.0 MPa for cube CB1.0SF. The lowest compressive strength at the age of 7 days was the control cube CB0.0SF which was 43.1 MPa. This shows an increase of 13.7% in the compressive strength for steel fibre concrete. The compressive strength of cube CB2.0SF at the age of 7 days was 44.7 MPa in which recorded a slightly higher by 3.7% compared to control cube CB0.0SF. At the age of 28 days, the average compressive strength of each cube was found to be varied. The highest compressive strength was for cube CB1.0SF which was 66.8 MPa and the lowest value of 54.8 MPa for cube CB0.0SF with an improvement in the compressive strength by 21.8%. The compressive strength of cube CB2.0SF was 55.1 MPa with slightly increase by 0.5% compared to control cube CB0.0SF. The optimum dosage of steel fibre was found to be 1%. It was also observed that after the compression test, part of the concrete surface of the control cube CB0.0SF was spalled off but not for cube with fibre due to the bridging effect of the steel fibre as shown in Figure 3.

Table 3: Results of cube compressive strength of all concretes

Cube Identification	Fibre Percentage (%)	Age (days)	Average Compressive Strength (MPa)	Percentage Improvement (%)
CB0.0SF	0	7	43.10	-
		28	54.85	-
CB0.5SF	0.5	7	44.89	4.2
		28	66.70	21.6
CB1.0SF	1.0	7	49.00	13.7
		28	66.82	21.8
CB1.5SF	1.5	7	47.37	9.9
		28	62.86	14.6
CB2.0SF	2.0	7	44.70	3.7
		28	55.13	0.5

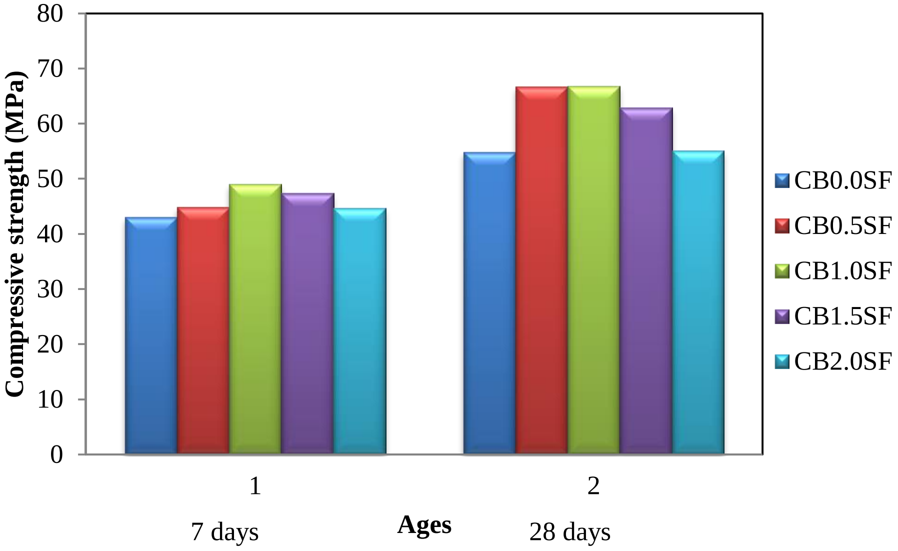

Figure 2: Compressive strength of all concretes versus age

Figure 3: Failure of control concrete (left) and steel fibre concrete (right)

3.2 Ultrasonic Pulse Velocity Test (UPV test)

The UPV test, measured at different locations, was conducted to study the distribution of steel fibres inside the concrete prisms. The UPV test results of all concretes are summarized in Table 4. In order to make clear comparisons, the relationship between time and location of measured UPV value on the prism is shown in Figure 4. Figure 4 shows that the time for the pulse to travel along different type of concrete prism was varied and most likely due to the presence of the fibres. The control prism P0.0SF with no steel fibres recorded less time for the pulse to travel compared with other prisms with steel fibres. The time recorded for prisms with fibres was slightly higher compared to the control prism. This variation in travelling time was probably due to the loss of energy during the travelling of the pulse through the concrete prism caused by the randomly distributed steel fibres inside the concrete.

Table 4: Results of UPV Test

Prism / Position	P0.0SF	P0.5SF	P1.0SF	P1.5SF	P2.0SF
1	174.3	175.4	180.8	176.6	180.8
2	175	177.3	181.5	178.2	179.9
3	176.3	175.6	178.2	179.9	181.8
4	174.3	175.2	180.5	176.6	180.9
5	174.2	176.4	181.5	178.9	182.1
6	173.4	174.4	178.6	179.9	180.3
7	177.2	176.5	181.2	179.2	180.5

Note: all units are in μs.

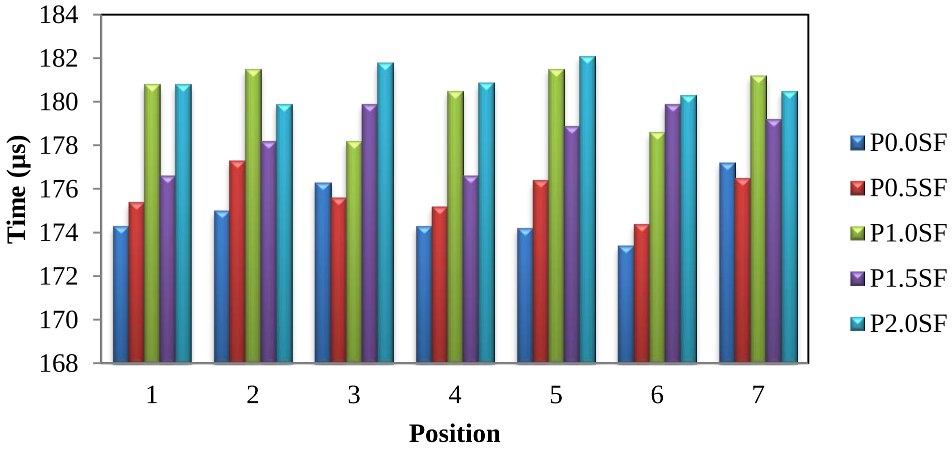

Figure 4: Time of pulse recorded at different location for all prisms

3.3 Rebound Hammer Test

The rebound hammer test was conducted to determine the correlation of the compressive strength with the rebound number. The concrete compressive strength was determined by using the portions of broken prism tested in flexure (Equivalent cube method). The results of rebound numbers for each prism are summarized in Table 5. The correlation of the compressive strength with the rebound number is shown in Figure 5. It can be seen that the rebound hammer value increases as the compressive strength of concrete increase. However, it was also found that there is no significant effect of steel fibres inclusion in concrete on the value of the rebound hammer as shown in the table.

Table 5: Results of rebound hammer test for all type of concretes

Prism Identification	P0.0SF	P0.5SF	P1.0SF	P1.5SF	P2.0SF
Global Average	35.6	35.5	36.6	36.9	37.5
Equivalent Compressive Strength (MPa)	38.8	61.4	74.2	72.3	69.2

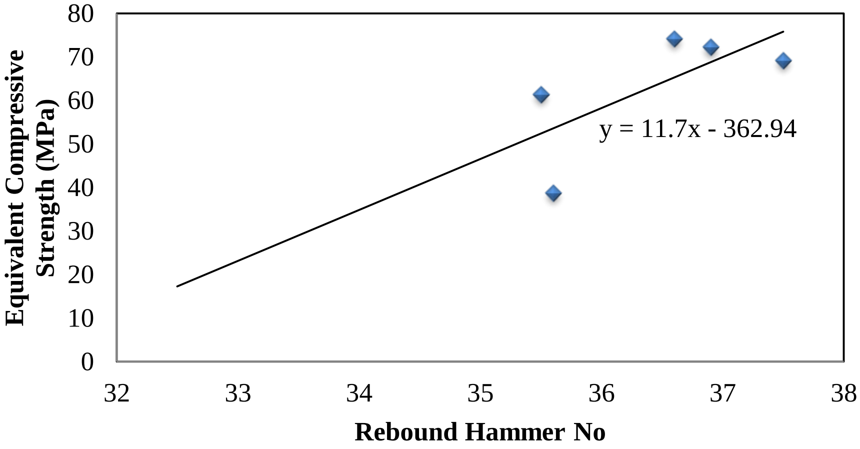

Figure 5: Relation between compressive strength and rebound hammer number

3.4 Flexural Test of Prisms

The load-deflection of all the prisms tested is shown in Figure 6. It can be seen that by adding steel fibres in concrete, it can improve not only the ultimate load but also the flexural behaviour of the concrete prism. The control prism P0.0SF failed in a sudden manner in two parts at load of about 18.5 kN and the gradual load-deflection behaviour of the prism cannot be recorded compared to prisms with steel fibres. The load deflection behaviour of other prisms containing steel fibres was linear until the prism failed in flexural-tension mode. Concrete prism P0.5SF recorded the maximum load carrying capacity of 19.0 kN or 2.7% higher than the control prism P0.0SF. the first crack was observed at about 14.3 kN load with 0.55 mm deflection. The cracks were generated nearby the mid span of the prism. Prism P1.0SF with 1% steel fibre recorded maximum load carrying capacity of 22.0 kN or 18.9% higher than the control prism. Compared to control prism, the first crack was recorded near the mid span of prism which was at load of about 22.0 kN. The prism failed in the mode of flexural-tension. Concrete prism P1.0SF has the ability to carry more loads compared to concrete prisms P0.0SF and P0.5SF as shown in Figure 6.

Prism with 1.5% steel fibre, P1.5SF, recorded maximum load carrying capacity of 18.5 kN similar to the control prism. When compared with control prism P0.0SF, the first crack occurred for prism P1.5SF was at load level of about 17.9 kN with recorded deflection of 2.46 mm. On the other hand, concrete prism P2.0SF recorded an improvement of 49.7% in the ultimate load compared to prism P0.0SF with the first crack occurred at load of about 27.7 kN. Concrete prism P2.0SF was found to be able to carry more loads before the first crack compared to prisms P0.0SF, P0.5SF, P1.0SF and P1.5SF as shown in Figure 6. This was due to the inclusion of steel fibres in the concrete. However, after the first crack load, the deflection of prism P2.0SF dropped dramatically compared to prisms P1.0SF and P1.5SF.

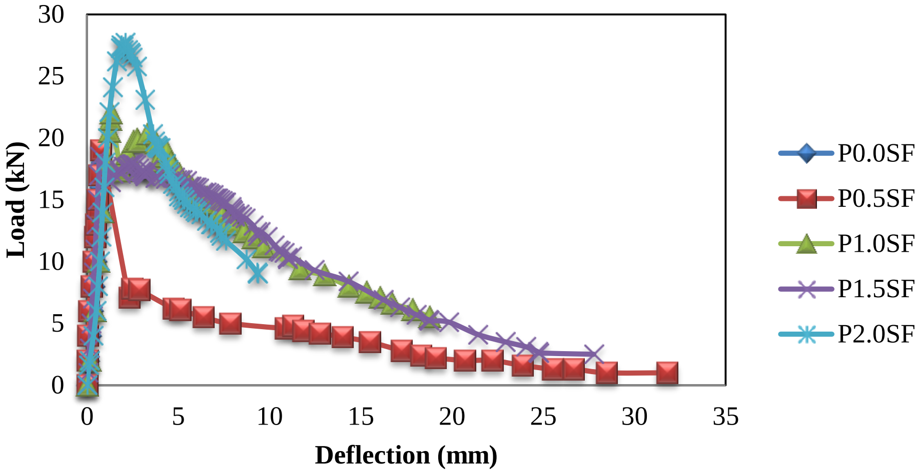

Figure 6: Load versus deflection of prisms

3.5 *Flexural Test of Slabs*

All concrete slabs were tested under flexure and their load-deflection behaviour is shown in Figure 7. It can be seen that by adding steel fibres, the ultimate strength capacity and flexural behaviour of the slabs were improved. For slab SC-PLAIN, there was no first crack generated and it fails in a sudden manner at load of about 17.7 kN. There was no load-deflection data recorded for the plain concrete beam SC-PLAIN due to sudden failure. In contrast, slab SC-R150 with tensile reinforcement bar at spacing of 150 mm, the first crack was found nearby the mid span of the slab at the load of about 18 kN with the deflection of 0.84 mm. The load deflection behaviour of the slab was linear until the first crack occurs. After that the load capacity was drastically dropped probably due to less bond strength between the plain tensile reinforcement and concrete before started to increase marginally until failure. Major crack was developed from the first crack near the mid span and an increase of load applied to the slab lead to the extension of the existing cracks until the load reached 17.9 kN and the slab then failed in the flexural-tension mode.

Concrete slab SB-R300-1SF with tensile reinforcement bar at 300 mm spacing and with 1% of steel fibres recorded an improvement in the ultimate load by 25% compared to control slab SC-R150. Compared to the control slab SC-R150, the first crack occurred earlier at load of about 16.9 kN with 0.94 mm deflection. All cracks were found nearby the mid span of the slab or between the two-point load. The slab SB-R300-1SF failed at load of about 22.5kN in the flexural-tension mode. On the other hand, slab SB-1SF without the tensile reinforcement bar but with 1% steel fibre content recorded an improvement in the ultimate load compared to slab SC-R150 but less than slab SB-R300-1SF. Slab SB-1SF recorded maximum load before failure of about 21.5 kN or 19.4% higher than the control slab. Compared to the control slab SC-R150, the first crack load was found at about 20.1 kN. An increase in load resulted more cracks developed near the major cracks before the slab failed.

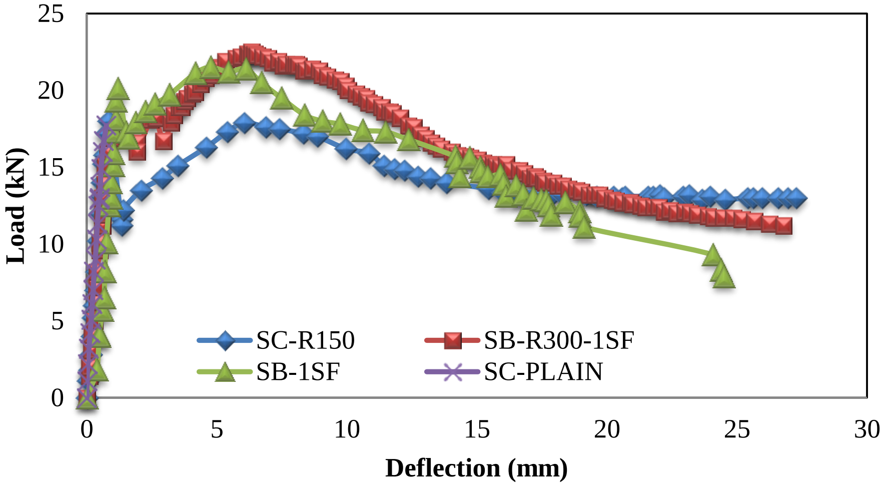

Figure 7: Load versus deflection for concrete slabs tested

3.6 Mode of Failure

Table 6 shows the description on the type of failure for all concrete slabs. Figure 8 shows the photo of the failure mode of all concrete slabs. The results of the test show that the reinforcement yielded before the concrete failed in compression as can be expected for the under-reinforced concrete slab. Figure 9 shows the failure mode of plain concrete slab without tensile reinforcement.

Table 6: Failure mode of all concrete slabs tested

Slab	Mode of Failure	Description
SC-R150	Flexural / Tension	Reinforcement yield before concrete failed in compression zone
SB-R300-1SF	Flexural / Tension	Reinforcement yield before concrete failed in compression zone
SB-1SF	Flexural / Tension	Pulling out of fibres before concrete failed in compression zone
SC-PLAIN	Flexural / Tension	Concrete failed suddenly without any sign

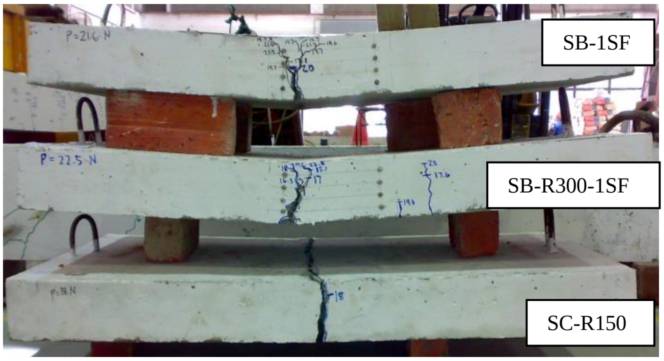

Figure 8: Failure mode of all steel fibre reinforced concrete slabs

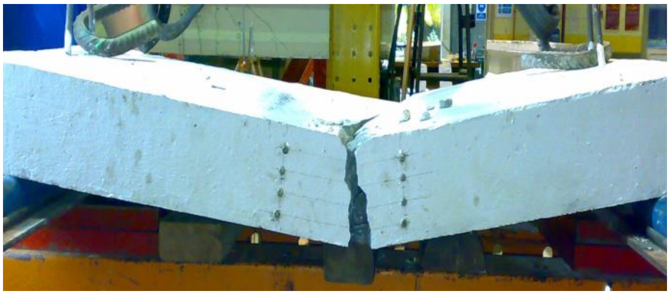

Figure 9: Failure mode of plain concrete slab (SC-PLAIN)

4.0 Conclusions

The conclusions that can be drawn from this study are as follows:

i. A suitable amount of optimum fibre dosage of 1% was found to enhance the properties of concrete. Higher dosage of steel fibres used in concrete mix, greater than 1% was found to decrease the strength of the concrete probably due to the balling effect in which the fibres are not distributed uniformly in the concrete mix.
ii. The inclusion of steel fibres was found to improve the cube compressive strength of concrete with ductile mode of failure, slightly lowered the UPV value but no significant effect on the rebound hammer results when compared to the control sample.
iii. The use of steel fibres not only can improve the ultimate strength capacity of the concrete prisms and slabs but also improve the flexural behaviour in terms of the stiffness and ductility of the samples.
iv. Slab SB-R300-1SF recorded the best performance compared to control slab SB-R150 and other slabs indicating that the addition of 1% steel fibres can be used in reducing the amount of tensile reinforcement in the concrete slab.

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