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The Robustness Of SteFib In Composite Structural Member

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Abstract

New technology and materials have been implemented to develop new findings for new research products. In line with the new achievement of Green Building in construction industries, researchers are trying to reduce wastage from construction material by adding new or special material as an admixture to replace or reduce the usage of conventional construction material. Steel fibre (**SteFib**) is one of the materials used as a replacement for reinforcement bars, either partially or totally, and known as steel fibre reinforced concrete (**SFRC**). **SFRC** has been widely used to improve resistance to cracking, ductility, energy absorption and impact resistance characteristics. **SFRC** can reduce or even eliminate cracking in concrete. In this study hooked end steel fibre with a 0.75mm in diameter and 60mm length was added into concrete beams and slabs to study the failure pattern and to investigate the ability of **SteFib** in increasing the flexural strength and preventing crack propagation in the structural member. Concrete of grade 30 with 25kg/m^3 and 30kg/m^3 fibre dosage were used in two beams and two slabs respectively. The Three Point Bending Test was carried out on all samples. Samples with **SteFib** embedded in concrete proved more effective in beams under flexural loads. High carrying capacity was found in beams with 50% ultimate load increment in **SteFib** beam. **SteFib** beams also showed high crack resistance by 80% and 87% the increment of crack length and crack width. The high strength and ductility of **SteFib** beams was shown at increments of 42% and 50% in strain and stress respectively.

Keywords

Flexural Capacity, Steel Fibres Concrete Panel, Carrying Capacity, Crack Control

1. Introduction

Steel Fibre (**SteFib**) is an additional material which helps to improve structural strength, reduce crack propagation and increase the durability of structural elements. However the application of steel fibre in construction industries is still limited since there are no specific codes or design practices implemented. Numerous researchers have been conducted with respect to use of **SteFib** in structural elements with beam (Özcan et.al., 2008; Hanai and Holanda, 2008; Campione, 2008; Altun et.al., 2006) and slab (Hanai and Holanda, 2008, Khaloo and Afhari, 2004). There are a few shapes of steel fibre available in construction industries, for example, corrugated steel fibre, crimped steel fibre, and hooked end steel fibre. This study will implement Hooked End Steel Fibre as additional reinforcement in a beam and slab to investigate the ability of **SteFib** in strengthening the flexural structural element and helping to reduce the structural failure.

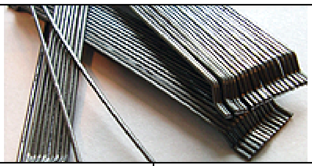
Application of **SteFib** is not limited to beam, slab, and column only. The most critical application of **SteFib** known is **SteFib** in the structural joint to help strengthen it (Somma, 2008; Shannag et.al., 2007; Smadi and Bani Yasin, 2007; Aiman and Nabawe, 2003; Nguyen et.al., 2010). The study (Nguyen et.al., 2010) indicated that **SteFib** improved from 9% to 39.8% in punching shear resistance of column-slab connection. The **SteFib** also helped improve the strength of the structural element, the durability and the stiffness (Shannag et.al., 2007). **SteFib** helped controled bending/deformation which also help to improve the durability by increasing the absorption energy under load increment (Nurharniza and Siti Hawa, 2009a; Nurharniza and Siti Hawa, 2009b, Olivito and Zuccarello, 2007). It is known that the ductility of **SFRC** increases by increasing the volume of **SteFib** from the same content and length (Olivito and Zuccarello, 2007). Beside that previous study found out that by increasing of **SteFib** volume would decreased the permeability of the cracked specimens due to crack stitching by the **SteFib** (Nurharniza and Siti Hawa, 2009a; Nurharniza and Siti Hawa, 2009b; Rapoport, 2002). Long **SteFib** may give higher bridging effect on crack which gives higher effect in reducing cracks from propagating. This paper discussed findings obtained through experimental investigation for flexural members involving beams and slabs which have been placed with **SteFib**.

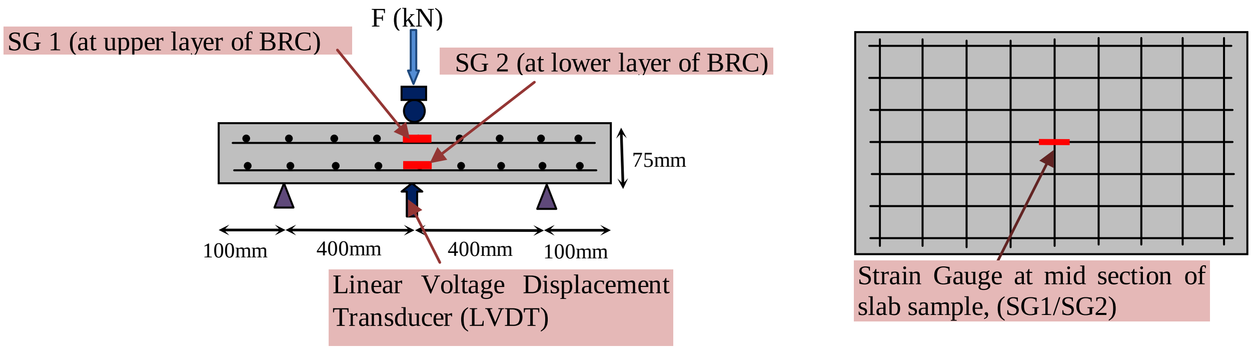
2.0 Experimental Works

A total of four samples have been prepared, two each, comprising slab and beam. Both sets have one control sample in which concrete of grade 30 were cast. The properties of **SteFib** used in this study are shown in Table 1. The size of slab was designed as $1000 \times 500 \times 75mm$ (length: width: thickness) reinforced in two layer rectangular mesh of B7. They were used in this study and consisted of 100mm of pitch length for longitudinal wires and 200mm of pitch length for cross wires. The characteristic strength of B7 was 485kN/mm^2 (Rapoport, 2002). Meanwhile the size of beam was designed as $1000 \times 250 \times 150mm$ (length: width: thickness). Reinforcement bars with 6mm diameter were used as the link and high yield reinforcement bars of 12mm diameter were used as main bar in beam. The main purpose of this study is to study the contribution of **SteFib** robustness in a structural member subjected to flexural load.

The details of slab and beam were shown schematically in Figure 1 and Figure 2 respectively. The yield strength of the reinforcement bar is 460kN/mm^2 (BS4449). The flexural test was set-up as a three point bending test as shown in Figure 1(a) and Figure 2(a). 5mm strain gauges with 120Ω capacity were used to measure deformation (strain) of reinforcement during experiment. The strain gauges were fixed at the maximum possible section for deformation. A Universal Testing Machine with ultimate loading capacity of 250kN (UTM250) was used for this set up. The load increment was set at 0.01mm/min with linear voltage displacement transducer (LVDT) set at mid-span underneath the sample to measure the displacement development.

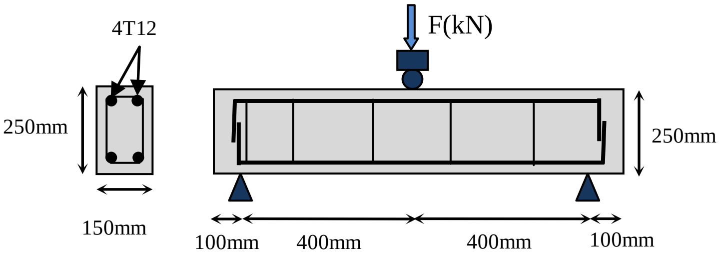
Table 1: Selected Steel Fiber Specification's

	
Designation	HE 0.75/60
Type	Hook End Steel Fibre
Fibre diameter, d	0.75 mm (± 0.05 mm)
Fibre Length, L	60 mm (± 2 mm)
Tensile strength of wire	Min 1200Mpa
Aspect Ratio (L/d)	80 (± 5)

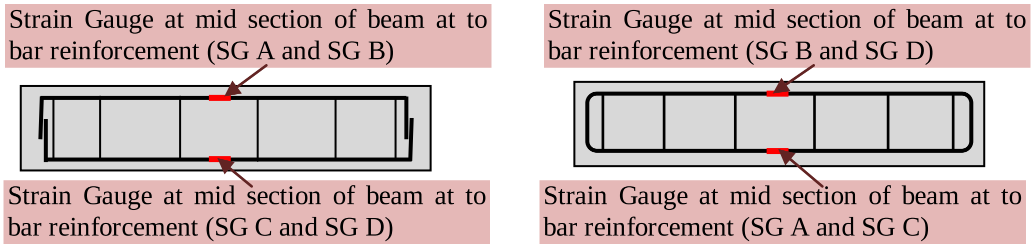


(a) Slab Detail and Experimental Set-up (b) Plan View of Slab Detail

Figure 1: Schematic Diagram for Slab



(a) Beam Detail and Experimental Set-up



(b) Rear View of Beam (c) Plan View of Beam

Figure 2: Schematic Diagram for Beam

3.0 RESULT AND DISCUSSION

Experimental results are discussed herein.

3.1 Material Properties

In this study, concrete was designed as grade 30 (30MPa). Four set of different dosage cubes were mixed with **SteFib** using 15kg/m^3, 20kg/m^3, 25kg/m^3 and 30kg/m^3. One set of normal concrete mix was done as a control sample. Cube size of $100 \times 100 \times 100mm$ were used to reduced wastage. Slump tests (Figure 3) were done to determine the texture of the fresh concrete and its uniformity.

(a) Plain Concrete Slump Test (b) SFRC Slump Test

Figure 3: Slump Test

From the slump tests **SteFib** is seen to stiffen the concrete by mounting up on each other and bonding well in the concrete. The presence of **SteFib** helps enhance the concrete workability as additional surface area of **SteFib** may cause concrete mix to dry by absorbing the available free water. The slenderness shape of **SteFib** promotes an interlocking concrete matrix. It is seen that 30kg/m^3 **SteFib** dosage reduced about 93% of slumping. When compared with normal concrete with 30kg/m^3 **SteFib** dosage gave a true slump reading of 9mm. Compare with previous research by (Nurharniza and Siti Hawa, 2009a), additional **SteFib** dosage 30kg/m3 into normal concrete grade 30 gives a slump test result of 10mm. This difference of 1mm can be eliminated and the slump test result of concrete grade 30 with 30kg/m^3 **SteFib** dosage can be concluded is within this range.

Normal cube tests are done for 7 days, 14 days, 21 days and 28 days. However previous research (Nurharniza and Siti Hawa, 2009a) found out that additional **SteFib** helps to increase the strength of the concrete beyond 28 days, 42 day cube tests were carried out.

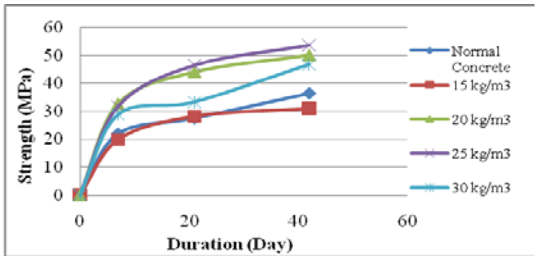


Figure 4: Cube Test result

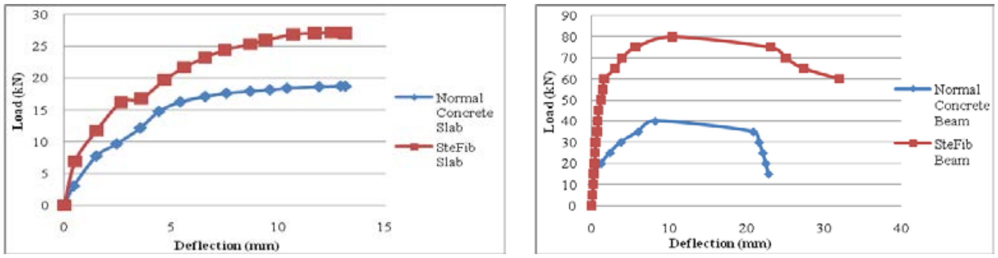
Based on the compression test results (Figure 4), 25 kg/m^3 **SteFib** gave optimum strength of 53.63kg/m^3 which are 32% higher when compared to normal cube 36.50 kg/m^3. However, compared with the previous study by (Nurharniza and Siti Hawa, 2009a) shows that 30 kg/m^3 **SteFib** dosage is optimum at 47.45kg/m^3 compressive strength due to distribution of **SteFib** in the mix. When comparing the study by (Nurharniza and

Siti Hawa, 2009a) to this study, a difference of 12% is obtained from the compressive strength. The difference is due to the distribution of **SteFib** in the mix. Homogeneity contributed to high energy absorption which in turn increases the compressive strength. A bad dispersion of fibres in the concrete may influence the concrete strength due to clots, a great number of voids and larger fibre volume which affects the homogeneity (Oliveira et.al., 2007). Based on these experiment results, a dosage of 25kg/m^3 was chosen for this study as it is more cost effective and yet capable of withstanding notable/ significant strength when compared to dosage of 30kg/m^3.

Table 2: Compression Test of Concrete Cube

Steel Fibre Dosage	Samples	Slump (mm)	f_{cu} at 7 days (N/mm^2)	f_{cu} Average at 7 days (N/mm^2)	f_{cu} at 21 days (N/mm^2)	f_{cu} Average at 21 days (N/mm^2)	f_{cu} at 42 days (N/mm^2)	f_{cu} Average at 42 days (N/mm^2)
Plain (0 kg/m^3)	A1	130	20.17	22.04	26.15	27.62	36.00	36.50
	A2		24.17		27.92		31.79	
	A3		21.79		28.80		36.10	
15.0 kg/m^3	B1	160	20.39	19.87	27.96	28.22	26.54	31.03
	B2		18.41		27.72		30.72	
	B3		20.80		28.99		31.79	
20.0 kg/m^3	C1	15	33.14	32.74	42.26	44.16	49.80	50.18
	C2		32.35		45.70		46.91	
	C3		32.74		44.53		50.55	
25.0 kg/m^3	D1	10	33.70	31.78	45.20	46.45	54.89	53.63
	D2		29.18		44.56		49.71	
	D3		32.46		49.58		52.37	
30.0 kg/m^3	E1	9	28.19	28.73	23.74	33.26	46.42	46.66
	E2		29.35		38.70		41.63	
	E3		28.64		37.33		46.90	

3.2 Ultimate Load and Deflection



(a) Slab Panel (b) Beam Panel

Figure 5: Load Vs Deflection

Table 3: Experimental Ultimate Load and Deflection

	Slab Panel		Beam	
	Load (kN)	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**
Theoretical	6.74	2.15	17.86	10.30
Normal Concrete	18.76	12.90	40.00	8.22
SteFib	21.13	12.50	80.00	10.40

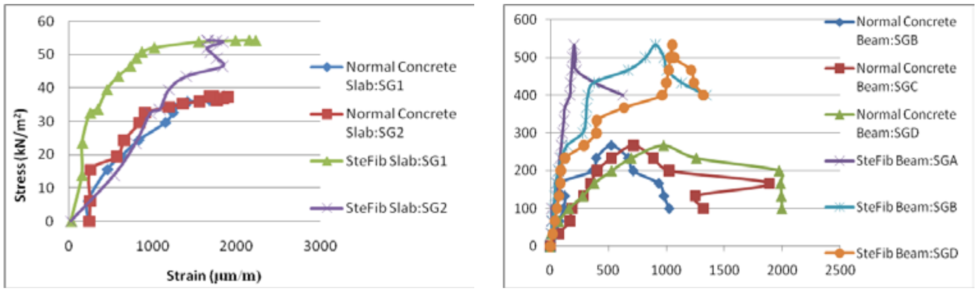
Figure 5(a) shows the load-deflection relationship for slab panels under the Flexural Bending Test. The load-deflection relationship shows linear relationships up to 9.76kN for normal concrete slab and 11.72kN for

SteFib slab until cracks start to emerge on slab surfaces and were followed by a nonlinear relationship onwards. The theoretical load calculation is 6.74kN with 2.15mm theoretical deflection. Experiment deflection for normal concrete and **SteFib** slab at the same load as theoretical calculation is 1.28mm and 0.49mm respectively. High displacement control is shown in **SteFib** slabs with an 83% increment of deflection compare with theories showing that **SteFib** helps increase the strength of slabs. Table 3 shows the ultimate load is 18.76kN with an associated deflection of 12.90mm for normal concrete slab. As expected **SFRC** slab shows an 11% increment in the ultimate load as an increase to 21.13kN with 12.5mm deflection compared with the normal concrete slab.

Similar patterns were found in experiment result for normal and **SteFib** beams under flexural loads (refer Figure 5b). The normal beam concrete relationship shows a linear relationship up to 15kN and 60kN for **SteFib** beam until cracks start to emerge on the beam surface and is followed by nonlinear relationship onwards until the beam failed. The theoretical load calculation is 17.86kN with 10.30mm theoretical deflection. At the same load level as theoretical calculation, experiment deflection for normal concrete and **SteFib** beam is 0.79mm and 0.32mm respectively. High displacement control is shown in **SteFib** beams with 97% reduction of deflection compared with the theoretical at the same load level as the theoretical. It is shown that **SteFib** helped increase the stiffness of the beam. Table 3 shows the ultimate load is 40kN with an associated deflection of 8.22mm for normal concrete beam. As expected, the **SFRC** beam shows a 50% increment in ultimate load capacity, as an increase to 80kN with 10.4mm deflection.

Based on the ultimate load and deflection of slabs and beams under Flexural Bending Test, **SteFib** may help to increase the ultimate load due to **SteFib** distributed evenly in structural panels and contribute to high energy absorption. The same condition is supported by (Byung, 1992) where the ultimate resistance of fibre-reinforced concrete beams is increased with an increased of fibre content. With the presence of **SteFib** in concrete structures a large load carrying capacity can be developed at a large deformation and this circumstance, also supported by (Dramix, 2003) found from large load carrying capacity with large deformation was performed in large areas of the structural element.

3.3 Stress-Strain



(a) Slab Panel (b) Beam Panel

Figure 4: Stress Vs Strain Relationship of Slab Panel

Table 4: Experimental Stress and Strain Value

	Slab			**Beam**				
	Stress (kN/m^2)	**Strain (µm/m)**		**Stress (kN/m^2)**	**Strain (µm/m)**			
		SG1	**SG2**		**SG A**	**SG B**	**SG C**	**SG D**
Normal Concrete	37.52	1848	1721	266.67	-NA-	-526	715	977
SteFib	54.26	2153	1656	533.33	-204	-905	-NA-	1052

The experimental test shows that the maximum stress for a **SteFib** slab is 54.26kN/m^2 which is 45% higher than a normal concrete slab (refer to Table 4). Added the strain value of a **SteFib** slab slightly reduced by 14% for SG1 but increased by 4% for SG2 when compared to normal concrete slabs. The experimental result showed that **SteFib** helps to increase the durability of slab panels by increasing the stress capacity and protecting the BRC by reducing 14% of the strain of BRC at a compression area of 11% of the load increment. On the other hand four strain gauges were used in beam panels as shown in Figure 2. However in normal concrete beam panels SG A was not functioning while SG C was not functioning in **SteFib** beam panels. Maximum stress for 533.33kN/m^2 is a 50% increment compared with normal concrete beam as shown in Table 4. Strain values also show that **SteFib** strain values are leading when compared with normal concrete beams. 42% of the strain increased at compression area (SG B) with the presence of **SteFib** in beam for a 50% load increment was found in **SteFib** beam.

Generally **SteFib** shows the ability of reducing the stress of structural panels. The high stress in **SteFib** panels with high reduction of strain value shows that **SteFib** is able to protect the reinforcement by absorbing high energy loads before the load is transferred to the reinforcement. **SteFib** helps to distribute the stress evenly throughout the material and was proven by the incremental stress capacity of **SteFib** slabs compared with normal concrete slabs as proved by (Rapoport, 2002). The same condition is also found in (Nurharniza and Siti Hawa, 2009a; Nurharniza and Siti Hawa, 2009b) where a higher stress capacity was found in slabs and beams under Flexural Bending Test with additional **SteFib** in the structural panels.

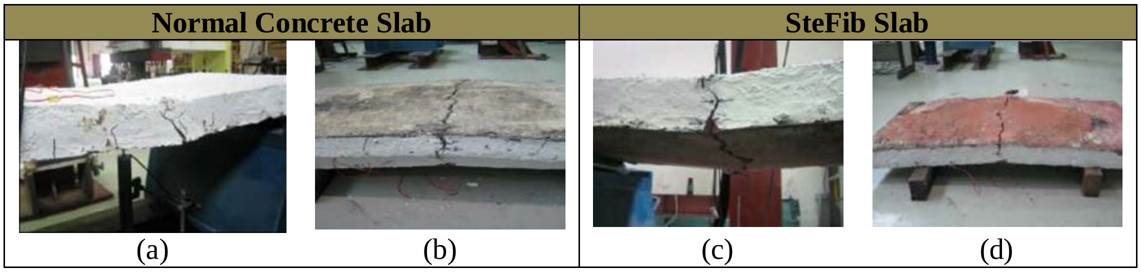
3.4 Crack Propagations

Table 5: Crack Length and Crack Width

	Maximum Crack on Slab Panel		Maximum Crack on Beam Panel	
	Length (mm)	**Width (mm)**	**Length (mm)**	**Width (mm)**
Normal Concrete	80	12	290	225
SteFib	60	7	58	30

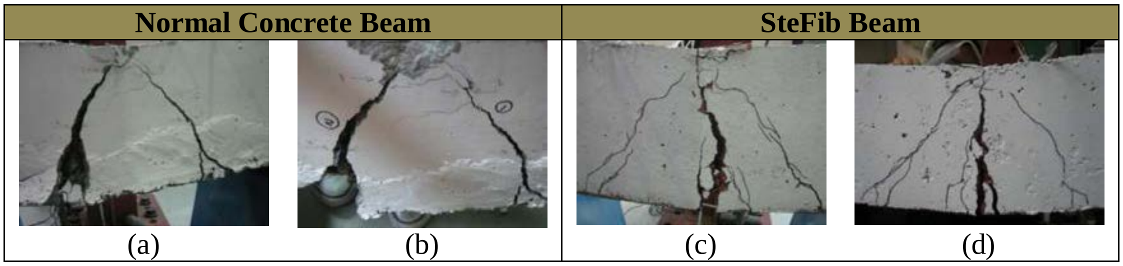
Experimental results show that normal concrete slab start to crack at 9.76 kN with deflection of 2.45mm. **SteFib** slabs start to crack at the higher load of 11.72kN with deflection of 1.50mm. Major crack occurred at mid span on slabs with hairline crack dispersed along the span of slab in normal concrete slabs. However, there is only one major cracks occurred at mid span on the **SteFib** slab's and no hairline crack was observed. Figure 7(a) shows normal concrete slab failed to resist tensile stress and developed extensive crack formation on the tension surface. Nevertheless, **SteFib** beams reduced 25% crack length and 42% reduction of crack width. The theoretical crack width is calculated to be in range of 0.05mm to 0.18mm. Therefore, the experimental result is way too high from the theoretical calculation. Major cracks occurred along the mid section of all samples. However, in the normal concrete sample the cracks initiated as hairline cracks on the slab panel as shown in Figure 7(b). On the contrary, the **SteFib** slabs developed major cracks failures at the mid section of the slab panel (Figure 7(d)). **SteFib** helped to stitch the cracks and reduced hairline crack development into wider cracks as proven in (Nurharniza and Siti Hawa, 2009a). This means that **SteFib** slabs sustained more energy absorption and contributed to a higher ultimate load as discussed earlier.

The initial crack load for normal concrete beams is at 15kN with 0.17mm deflection while crack load for **SteFib** beams is 35kN with 0.73mm deflection. Similar pattern of crack was found in beam where major crack was observed in normal concrete beam at mid section of beam. In contrary **SteFib** beams showed that, there is hairline cracks were observed in beam. However, **SteFib** beams shows 80% and 87% reduction in crack length and width respectively. Theoretical crack width gives in the range of 0.1 to 0.15mm. Therefore, the experiment result is way too high from the theoretical calculation. Major crack was observed in normal concrete beam at mid section of beam. The crack patterns for beams (Figure 8) confirmed the finding which showed that the **SteFib** play important role in reducing crack propagation or will slow down the crack dissemination in flexural member. Even though shear cracks occurred in all beams, the presence of **SteFib** helps to reduce the length and width of the cracks. Previous study also found that **SteFib** help in reduced the average crack width for concrete up to 75% (Nguyen et.al., 2010; Oliveira et.al., 2009). (Rapoport, 2002) found out that **SteFib** helps to change the crack geometry from one large crack to multiple smaller cracks and this condition in the end may stop the crack from propagating further.


Normal Concrete Slab **SteFib Slab**

(a) (b) (c) (d)

Figure 7: Crack Pattern on Slab Panel


Normal Concrete Beam **SteFib Beam**

(a) (b) (c) (d)

Figure 8: Crack Pattern on Beam Panel

4.0 CONCLUSION

An over view of these experimental results shows that generally **SteFib** may help to increase the durability of structural performance through high energy absorption on concrete with a load increment of 11% in slabs and 50% in beams compared with normal concrete panels. **SteFib** also may indirectly increase the strength of concrete structures. It is proven by 31% and 50% of stress increment being received in **SteFib** slabs and **SteFib** beams respectively due to flexural load increment. This high stress absorption is due to fibre distributed homogenously in concrete to help absorb stress under flexural conditions. The increment of the strain on the other hand showed that **SteFib** helped absorb high energy load in structural panels before it reached the reinforcement. Higher strain increments in compression areas were observed at SG 1 in slabs (14%) and SG B in beams (42%). Even though from the observation the number of cracks shows the increment for **SteFib** beams, however the ultimate load, deflection value and stress value increase due to load increment. 25% reduction of crack length and 42% reduction of crack width in **SteFib** slabs were observed. **SteFib** beams showed 80% and 87% reduction of crack length and width respectively. These conditions proved that the presence of **SteFib** may react as a hook to the crack from further disseminating.

5.0 ACKNOWLEDGEMENT

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