

Steel Fibres as Flexural Cracks Inhibitor in Reinforced Fibrous Concrete Beams under Static Loading

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ABSTRACT: The introduction of steel fibres in concrete beam has been proposed as flexural cracks inhibitor. This research was conducted focusing on simply supported beam to determine the crack propagations in flexure by varying the steel fibre content placement in the beam. The 25 kg/m³ steel fibre was chosen. Seven sets of 150×250×1000mm concrete beams consists of three RC beams with full steel fibrous concrete (SFRC), three RC beams with steel fibre placed within tension zone of the beam, three RC beams with steel fibre placed at the half of beam's tension zone, two conventional RC beams as control sample, one unreinforced concrete beam with full steel fibre, one unreinforced concrete beam with steel fibre at tension zone only and one unreinforced concrete beam with steel fibre at half of tension zone. The addition of steel fibre in the conventional RC beam showed that it inhibits the flexural cracks.

KEYWORDS: Steel Fibre, Steel Fibrous, Steel Fibrous Concrete, Flexural Cracks, Reinforced Concrete Beam, Steel Fibrous Reinforced Concrete Beam.

I. INTRODUCTION

Cracking is one of the common problems in the concrete structure. Structural members which are subjected to bending moment such as slabs and beams will develop flexural cracks. Flexural cracks occur when the stresses in the tension zone exceed the bending strength of the concrete. Flexural cracks on the sides of a beam start at the tension face and will extend, at most, up to the neutral axis. Crack widths will be greatest at the tension face and will reduce with distance from that face. In general, the cracks will be uniformly spaced along the most heavily loaded portion of the beam. Concrete is also known as a brittle material. By adding steel fibres in the concrete matrix improve the compressive, tensile and shear strength, durability and resistance impact because steel fibres restraining the mechanism of formation propagation, redistribute the forces within the concrete and the extension of cracks. This research is focused on a simply supported beam to determine the effect of steel fibre in reinforced concrete beam by analysing the crack patterns and to analyse and compare the crack propagation and flexural strengths of the reinforced concrete (RC) beam, steel fibrous reinforced concrete (SFRC) beam and steel fibrous concrete (SFC) beam. This study also is to evaluate the beams using finite element method.

II. RELATED WORK

The concept of using fibres in the concrete mix to improve the mechanical properties of concrete is known for many decades. Altunet. al [1] concluded that the mechanical properties of concrete with 30 kg/m³ steel fibre dosage is clearly better than concrete without steel fibre and concrete with 60 kg/m³ steel fibre dosage. Chang and Chai [2] found that the initial crack load of SFRC beam with steel content between 1.0% to 1.5% volumes increased 2 or 2.5 times from the RC beam. Hamid [3] found that concrete with 1% volume fraction of steel fibres improved in mechanical properties, flexural and compressive strength, first crack and ultimate load compared to RC beam. Ibrahim

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

and CheBakar [4] concluded that SFRC beam with 1% and 1.25% resulted in the increase of the splitting tensile strength and flexural strength. According to research by Norharyati [5], Hamid [3], Ibrahim and CheBakar [4], MohdYuasrizamet. al [6] and MohdYuasrizam et. al [7], the 25 kg/m³ or 1.0% volume steel fibre dosage gives the optimum compressive strength compared to other dosage. Khalooet. al [8] determined that the splitting tensile strength, flexural strength and toughness increased by increasing the steel fibre percentage. Padmarajaiah and Ramaswamy [9], Altunet. al [1], Özcan et. al [10], Hamid [3] and Marta Słowik and Tomasz Nowicki [11] used four points bending test rather than three points bending test in which the beam is longer than 1 m. However, Mujika [12] was found that the flexure modulus calculated on four points bending test without correction for both test methods is overestimated. All the past researchers used full steel fibrous concrete beam as the test specimens. Padmarajaiah and Ramaswamy [9] and Özcanet. al [10] used ANSYS software to validate their experiment results through finite element analysis. Meanwhile, Marta Słowik and Tomasz Nowicki [11] used ABAQUS software for their validation.

III. METHODOLOGY

This research is focused on the effectiveness of using steel fibrous concrete in the concrete beam in order to reduce the crack propagation in the concrete beam. Structural member were designed using f_{cu} of 30 N/mm² and f_y of 460 N/mm². The concrete mixing contain of Ordinary Portland Cement (OPC), water, normal coarse aggregate and sand. All the materials need to be prepared first before any concrete laboratory works can be conducted. The laboratory work that involved in this study which involving concrete is slump test, casting and curing, concrete cube compression test and three point bending test. Other laboratory works that need to be conducted is reinforcement tensile test and bending test. Crack load, ultimate load, deflection and crack propagation will be monitored throughout the flexural test to obtain the comparisons between all beams performance during flexural loading. Finally, a finite element analysis will be evaluated by using ANSYS software to compare with the results from three points bending test.

Laboratory Work

Laboratory works that are involved in this research are casting and curing concrete cube, slump test of concrete, concrete cube compression test, reinforcement bar tensile test, reinforcement bar bending test and three point bending test of the seven sets of concrete beams. Materials compliance tests were conducted accordingly for concrete and steel reinforcement. BS1881 [13] and MS26 [14] specify the use of concrete cubes for determining compressive strength using 100×100×100mm cubes for quality control purposes. The compression test was conducted in order to determine the compressive strength (crushing strength) of concrete test cube according to BS1881:Part 4:1970 [13] or MS26:Part 2:1991 [14] for 7 days, 14 days and 28 days comprises of plain concrete as control sample and concrete containing of 25 kg/m³ steel fibre. Reinforcement tensile and bending test were tested according to BS4466:1997 [15]. For this research, reinforcement bar grade 250 N/mm² uses bar of 6 mm as shear links and reinforcement bar grade 460 N/mm² uses bar of 10 mm as top and bottom reinforcing steel.

Preparation of Beam Specimens

The plain RC beams and SFRC beams were cast as the usual procedure. However, in the SFRC (TZ) beams, the pouring was done in stages. The steel fibrous concrete mix was first pour into the formwork to the height of 125 mm complying with the tension zone position of the beam and then allowed to set before topping up with the plain concrete mix. The set time is short enough as not to allow formation of separation between the two mixes but appropriate to let the steel fibre remain in the tension zone only. Meanwhile, casting procedures for SFRC (HTZ) beams is similar to casting procedures for SFRC (TZ) beams. In SFRC (HTZ) beams, the steel fibrous concrete mix is poured into the formwork to the height of 62.5 mm complying with the half tension zone. Subsequently the plain concrete mix is poured after steel fibrous concrete mix is slightly set. The setting time is limited to within 45 minutes to ensure the good bonding between plain concrete and steel fibrous concrete. Concrete mixing should be controlled to avoid multiple mix so that freshly mixed concrete before and after mixing when cast it is homogenous. This

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

adhesive failure during placing is generally called as cold joint phenomena. Cold joint phenomenon is a phenomenon where there is separation between two mixes.

Flexural Test of Concrete Beams

Flexural tests are conducted on the simply supported RC beams, SFRC beams and SFRC (tension zone) beams. They were loaded with point load at mid span. The resulting bending moments induce compressive stresses at the upper side and tensile stress at the underside of the beam. Crack propagations were monitored and measured. Strain gauges of 120 Ω and 5 mm length were bonded onto the longitudinal steel bar at mid span of the steel cage, two on the tensile bars and another two on the compression bars. The tests were carried out by imposing displacement rate of 0.01 mm/sec using Universal Testing Machine with maximum load 250 kN. The load versus deflection graph, crack pattern and width, length of crack and cracking load, configuration of failure and defect in sample due to design and testing has been included in this paper. Figs. 1 and 2 show the schematic diagram of the beam sample and the three points bending test experimental set up for the simply supported beam respectively.

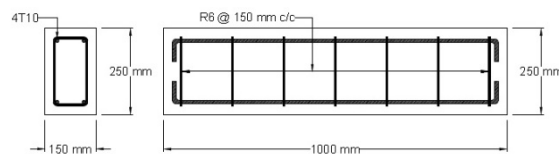


Fig. 1: Schematic diagram of sample

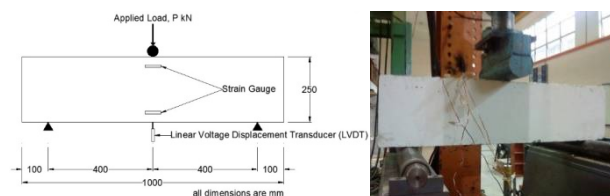


Fig. 2: Three points bending test experimental set up for simply supported beam.

Finite Element Method

For this study entitled steel fibres as flexural cracks inhibitor in reinforced fibrous concrete beams under static loading, ANSYS is a large scale, general purpose, finite element computer aided engineering software that may be used to stimulate and solve a wide variety of problems from wide variety physics environments [16]. This study used ANSYS 14.5 under nonlinear solution and convergence criteria for the reinforced concrete solid elements were based on force and displacement and the convergence tolerance limits were initially selected by analysis program. The RC, SFRC, SFRC (TZ) and SFRC (HTZ) beams was tested in the laboratory under three point bending test and result was used as input data for finite element analysis to validate the results from experiment.

Material Properties

Two (2) material models, Solid65 and Beam188 are used. The Beam188 element is based on Timoshenko beam theory, suitable in analysing slender to moderately thick beam structures. It is a linear 2-noded beam element in 3D with six (6) degrees of freedom (DOF) at each node which include translations in x, y and z directions and rotations about x, y and z directions. The Solid65 element is used for the three-dimensional modelling of solids with or without reinforcing bars. Solid is capable of cracking in tension and crushing in compression. Solid65 element requires linear isotropic and nonlinear nonmetal plasticity. In linear isotropic, EX is the modulus of elasticity of the concrete (E_c) and PRXY is the Poisson's ratio (ν). The modulus of elasticity of the concrete, steel fibre concrete and reinforcement bar are obtained from the experimental results and used as input data, namely 30 N/mm², 48.335 N/mm² and 200 N/mm²

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

respectively. Meanwhile, Poisson's ratio is assumed to be 0.2. In the contrary, Beam188 elements require linear isotropic only which is the modulus of elasticity of steel and Poisson's ratio is 205 N/mm² and 0.3 respectively.

Geometry

The full size dimension of the beams is 150×250×1000 mm and the span between the two supports is 800 mm. By taking the advantage of the symmetry of the beam, half of the full beam was modelled as shown in Fig. 3 giving the modelled volume of 150×250×500 mm. Solid65 was used to create plain concrete and steel fibre concrete and Beam188 element was used to create flexural and shear reinforcements. Planes of symmetry were required at the internal faces because only half of the entire beam was used for the model. The displacement in the direction perpendicular to the plane was held at zero on the plane of symmetry

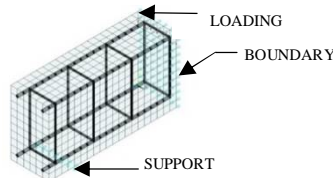


Fig. 3: Beam Model

Meshing

Rectangular mesh is recommended in order to obtain satisfactory results from the Solid65 element. The mesh setup was created using cubic elements of 25×25×25 mm. The necessary element division was noted. The reinforcement requires no specific meshing as individual element was created using nodes.

IV. EXPERIMENTAL RESULTS

Steel fibres helped to improve mechanical properties of concrete by decreasing the permeability of the cracks, making concrete more ductile, improving its durability appreciably and increasing the strength of the concrete. The experiments were expected to show that incorporating fibres into concrete matrix reduced the crack propagation and width due to the increasing in tensile strength of the fibrous concrete.

Compressive Strength of Concrete Cube

The characteristic strength for both batch designs is 30 N/mm² and the water cement ratio is 0.5. The concrete with steel fibre is stiffer than control sample making it less workable as steel fibre additions introducing more surface area absorbing the water. If water in the concrete with fibre is increase, the slump will increase and workability will be good but the strength of the concrete will decrease.

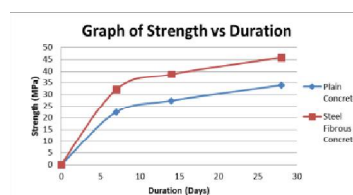


Fig. 4: Graph of compressive strength versus duration

Fig. 4 shows the result of compressive strength of the control samples and concrete with 1% steel fibre. The f_{cu} obtained for plain concrete (PC) and steel fibre concrete (SFC) is 12% and 35% increase from the design value respectively. According to the weight and volume of the concrete cubes, the density of plain concrete and steel fibre

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

concrete is 2451 kg/m^3 and 2466 kg/m^3 . The difference of density between plain concrete and steel fibre concrete is only 0.61%. It is shown that higher the density of concrete cube increase, the higher of compressive strength of the concrete cube will increase.

Ultimate Load and Deflections Curves

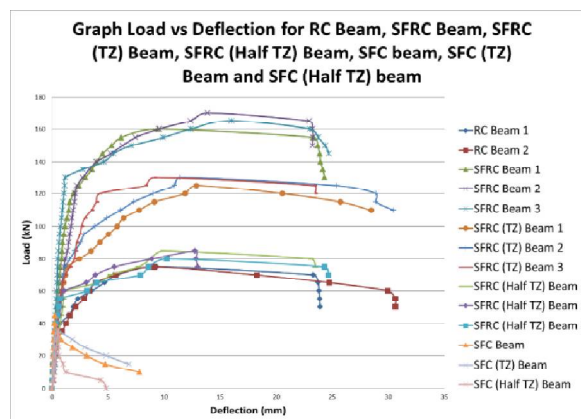


Fig. 5: Relationship between applied load and deflection

The graph of comparison of load versus deflection for all simply supported beams which are RC, SFRC, SFRC (TZ), SFRC (HTZ), SFC, SFC (TZ) and SFC (HTZ) beams when subjected to static loading is as shown in Fig. 5. All beams behave linearly during service until yield. The flexural behaviour of fibrous reinforced concrete, even when the fibre content by volume and the cross-sectional dimensions are the same, differs considerably between the case where the Young's modulus of the fibre is higher than that of the matrix and the case where it is lower.

Table 1: Load and deflection

Sample	P_{crack} (kN)	δ at P_{crack} (mm)	P_{yield} (kN)	δ at P_{yield} (mm)	P_{ult} (kN)	δ at P_{ult} (mm)	P_{theory} (kN)	δ at P_{theory} (mm)	P_{ult}/P_{theory}
RC Beam 1	30	0.59	40	0.74	75	9.33	90.98	18.76	0.82
RC Beam 2	30	0.41	30	0.41	75	9.11	90.98	18.76	0.82
SFRC Beam 1	70	0.67	120	1.93	160	9.44	125.14	18.76	1.28
SFRC Beam 2	65	0.93	125	2.22	170	13.88	125.14	18.76	1.36
SFRC Beam 3	75	0.49	130	1.20	165	16.01	125.14	18.76	1.32
SFRC (TZ) Beam 1	55	0.78	75	1.37	125	12.88	108.05	18.76	1.16
SFRC (TZ) Beam 2	60	0.85	75	1.18	130	11.44	108.05	18.76	1.20
SFRC (TZ) Beam 3	60	0.81	70	1.15	130	9.12	108.05	18.76	1.20
SFRC (HTZ) Beam 1	45	0.84	60	1.17	85	9.93	99.51	18.76	0.85
SFRC (HTZ) Beam 2	50	0.77	60	1.09	85	12.75	99.51	18.76	0.85
SFRC (HTZ) Beam 3	45	0.48	55	0.72	80	10.25	99.51	18.76	0.80
SFC Beam	30	0.15	45	0.25	45	0.25	45.00	-	1.00
SFC (TZ) Beam	25	0.20	35	0.48	35	0.48	37.50	-	0.93
SFC (HTZ) Beam	15	0.26	35	0.50	35	0.50	33.75	-	1.04

Table 1 shows the applied load at first crack, yield and ultimate along with its respective deflection during the experiment for all beams. For all RC, SFRC, SFRC (TZ) and SFRC (HTZ) beams, the load started to decrease when applied load reach the maximum strength and wider cracks were observed underneath the beams. The deflections

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

magnitudes indicated by these four beams represent the appreciative function of the steel fibre in significantly controlling the deflection. Addition of steel fibre control deflection with lesser magnitude than normal RC beam. It shows that steel fibrous reinforcement enhances both tensile strength and fracture energy so that it can improve the flexural strength to a much extent for normal concrete beam behaviour performance. In terms of strength, SFRC (HTZ) beam can resist more load than RC beam even though only one third of the beam contains steel fibres. Based on the concrete density, the SFRC beam which had higher concrete density can resist more flexural load compare to RC beam which had a lower concrete density.

Cracks Pattern

The theoretical crack opening was calculated to be 0.29 mm for all samples. All beams failed in flexure, evidenced through experimental observations in which the cracks appeared within the mid third span of the beams. The crack length ranged between 230 mm to 440 mm. With sample incorporating steel fibres has reduced crack formations and deformation characteristic. The random distribution of the steel fibre in reinforced concrete beam reduced the characteristic of the fracture as dispersion in concrete modified the cracks propagation by slowing the crack initiation. Table 2 shows the experimental result gathered based on the crack observed on the surface of the reinforced concrete beam.

Table 2: Crack length and crack opening

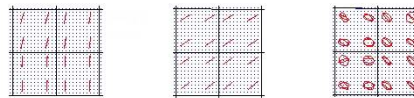
Sample	P _{crack} (kN)	Max. length of crack (mm)	Max. crack opening (mm)
RC Beam 1	30	230	25
RC Beam 2	30	318	30
SFRC Beam 1	70	440	15
SFRC Beam 2	65	330	24
SFRC Beam 3	75	260	27
SFRC (TZ) Beam 1	55	295	18
SFRC (TZ) Beam 2	60	280	21
SFRC (TZ) Beam 3	60	258	23
SFRC (HTZ) Beam 1	45	252	26
SFRC (HTZ) Beam 2	50	255	24
SFRC (HTZ) Beam 3	45	251	30
SFC Beam	30	250	13
SFC (TZ) Beam	25	249	10
SFC (HTZ) Beam	15	250	11

The steel fibres improved the brittleness of concrete to ductile by bridging the concrete matrix when the load applied to it, thus reduce the propagation of cracking in beam [5]. The proof come from the experimental work that have been mentioned that crack length in RC beam is wider than in the SFRC beams, SFRC (TZ) beams and SFRC (HTZ) beams. In addition, the steel fibres that randomly distributed in concrete beam form a better bonding between the fibres and matrix resulted in reducing the hairline cracks before further development into wider cracks. The experimental observation proved that steel fibres in the concrete beam act as crack arrester and give a good performance in controlling crack propagation at the tension zone remarkably high to increase the tensile strength in reinforced concrete beam. The crack patterns captured through finite element analysis is shown in Fig. 6. Figs. 7 to 10 show the close-up view of cracks patterns for the beams samples after testing and from finite element analysis.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016



(a) (b)(c)

Fig.6: Cracking signs

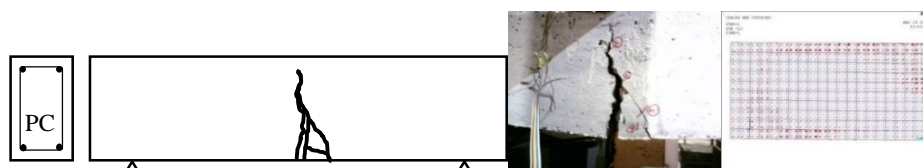


Fig. 7: Cracks pattern on RC beam



Fig. 8: Cracks pattern on SFRC beam

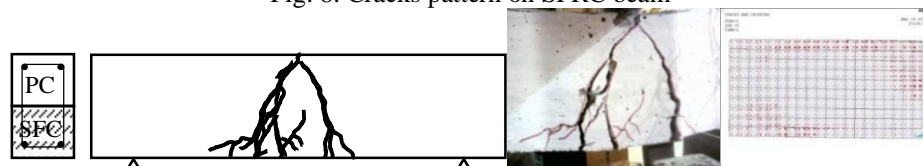


Fig. 9: Cracks pattern on SFRC (TZ) beam



Fig. 10: Cracks pattern on SFRC (HTZ) beam

During the analysis, all beams showed flexural crack initiated from the mid-span on the underneath surface of the beam. The crack signs appear as vertical lines. The crack mouth widens and penetrated into the beam, towards the compressive zones. The diagonal tensile cracks occurred at between support and mid span which occur mostly in the longitudinal direction. When the principal stresses exceed the ultimate tensile strength of the concrete, compressive cracks appear perpendicular to the principal stresses. It is seen that crack width and crack lengths between SFRC beam and SFRC (TZ) beam are similar. Although SFRC (TZ) beam can resist less maximum applied load compared to SFRC beam, the steel fibre placed at the tension zone only, can function similarly to SFRC beam. Steel fibre holds the concrete matrix well and reduces the flexural cracks propagation. All beams failed under flexure.

Stress, Strain and Displacement

Graph in Figs. 11 to 15 show the relationship between stress and strain of simply supported beam for RC beam 1 and 2, SFRC beam 1, 2 and 3, SFRC (TZ) beam 1, 2 and 3, SFRC (HTZ) beam 1, 2 and 3 and SFC beams respectively where initially the stress and strain behaves almost linearly until the concrete achieve the maximum stress. When maximum stress was reached, the stress decreased correlating to the increase of strain leading towards breakage. At this point, the beam experience strength degradation and reinforcement bars started to bend and beam tend to fail with severe rupture. The theory of bending for reinforced concrete assumes that the concrete will crack in the region of tensile strain and that, after cracking, all the tension is carried by the reinforcement (Mosley et. al, 1999). Strain gauges

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

1 and 2 were located on surface of tensile reinforcement bars while strain gauges 3 and 4 were located on surface of compression reinforcement bars. SFRC beam withstood greatest stress compared to RC beam, SFRC (TZ) and SFRC (HTZ) beam because it can sustain the highest applied load and deflection. On the other hand, the strain value recorded for SFRC beam, SFRC (TZ) beam and SFRC (HTZ) beam is much lower than the strain value for RC beam at the ultimate strength point. This represents that the amount of deformation of SFRC beam, SFRC (TZ) beam and SFRC (HTZ) beam body due to an applied force is less compare to RC beam.

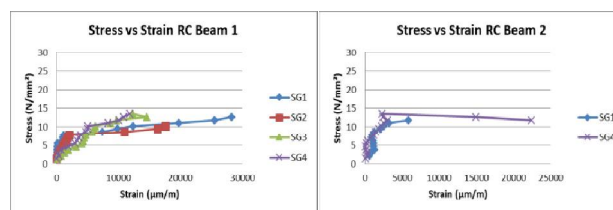


Fig. 11: Graph of Stress versus Strain for RC Beam

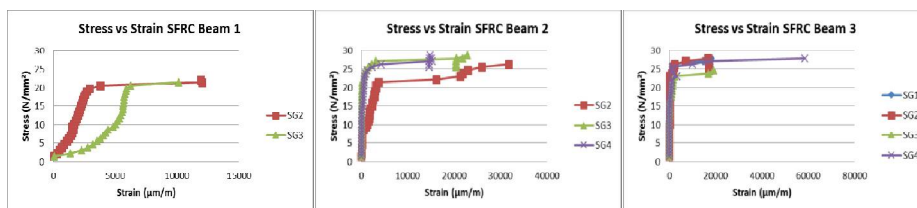


Fig. 12: Graph of Stress versus Strain for SFRC Beam

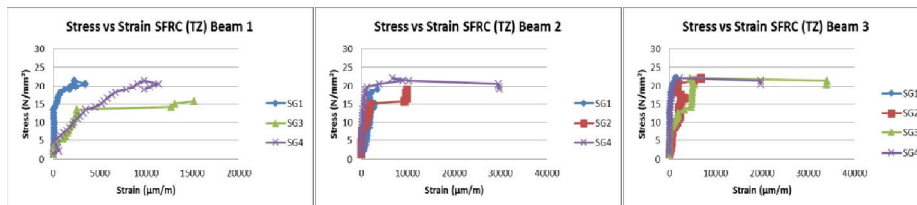


Fig. 13: Graph of Stress versus Strain for SFRC (TZ) Beam

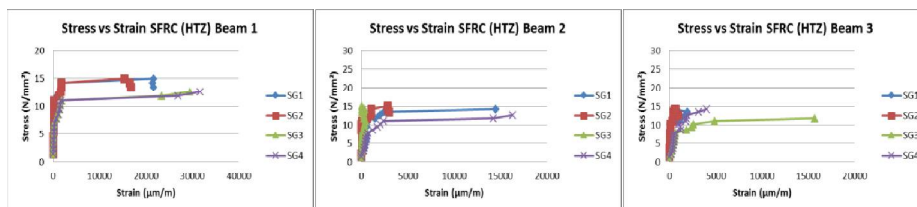


Fig. 14: Graph of Stress versus Strain for SFRC (HTZ) Beam

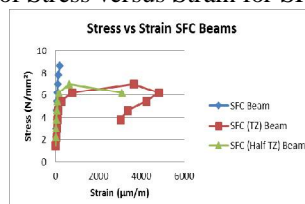
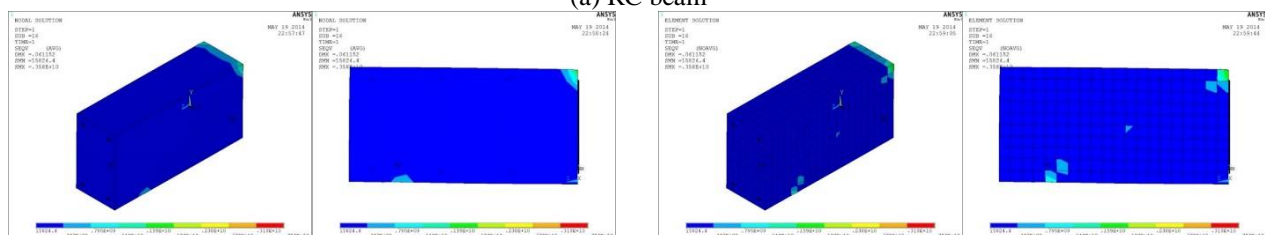


Fig. 15: Graph of Stress versus Strain for SFC Beams

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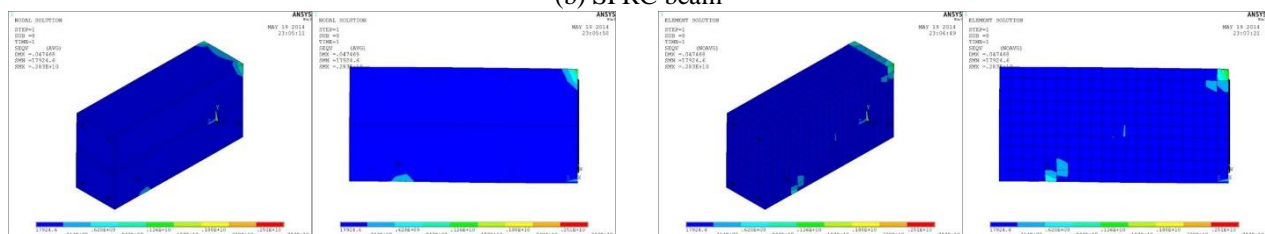
(ii) Element solution

(a) RC beam



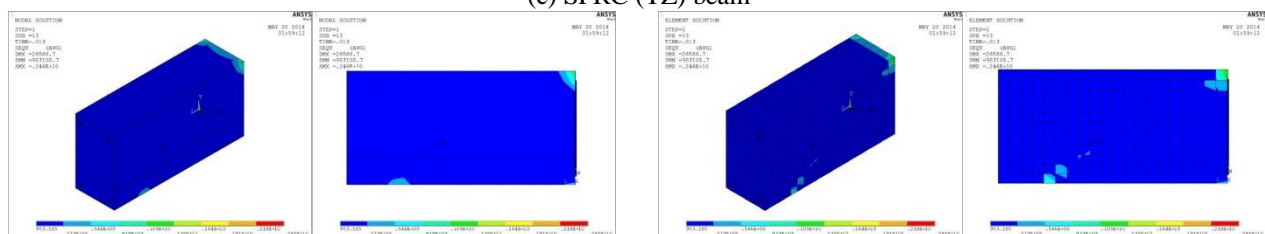
(ii) Element solution

(b) SFRC beam



(ii) Element solution

(c) SFRC (TZ) beam



(ii) Element solution

(d) SFRC (HTZ) beam

Fig. 16 : Maximum compressive stress and tensile stress

Table 3: Maximum stresses

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Sample	Experiment		Finite Element Analysis					Experiment vs Finite Element Analysis	
	Ultimate Flexural Stress (N/mm ²)	Maximum Displacement (mm)	Stress				Maximum Displacement (mm)	Stress (%)	Maximum Displacement (%)
			Nodal Solution		Element Solution				
			Compressive Stress (N/mm ²)	Tensile Stress (N/mm ²)	Compressive Stress (N/mm ²)	Tensile Stress (N/mm ²)			
RC Beam 1	13.43	9.33	17.7	0.00012	17.7	0.00012	7.351	32	24
RC Beam 2	13.43	9.11						32	21
SFRC Beam 1	27.03	9.44	35.8	0.00016	35.8	0.00016	61.152	28	147
SFRC Beam 2	28.63	13.88						22	126
SFRC Beam 3	27.83	16.01						25	117
SFRC (TZ) Beam 1	21.43	12.88	28.3	0.00018	28.3	0.00018	47.468	28	114
SFRC (TZ) Beam 2	22.23	11.44						24	122
SFRC (TZ) Beam 3	22.23	9.12						24	136
SFRC (HTZ) Beam 1	15.03	9.93	24.6	0.009	24.6	0.009	14.241	48	36
SFRC (HTZ) Beam 2	15.03	12.75						48	11
SFRC (HTZ) Beam 3	14.23	10.25						53	33

According to the finite element analysis, the compressive stress and tensile stress is increase according to higher steel fibre portion as shown in SFRC beams recording 35.8 N/mm². Similar trend is seen in the experimental results. Magnitudes from the numerical modelling are optimistic over the experimental results. However, the SFRC (HTZ) shows the largest difference for stress, accounting to 53%. The strength is higher due to the stiff mixture. It shows that the steel fibre in RC beam increase the bond between the concrete matrixes thus retaining higher load compared to the plain RC beam. Similarly, the addition of steel fibre increases the resistance of the RC beam in terms of displacement. The maximum displacement on RC beam, SFRC beam, SFRC (TZ) beam and SFRC (HTZ) beam under maximum stress is as shown in Table 3 and Fig. 17.

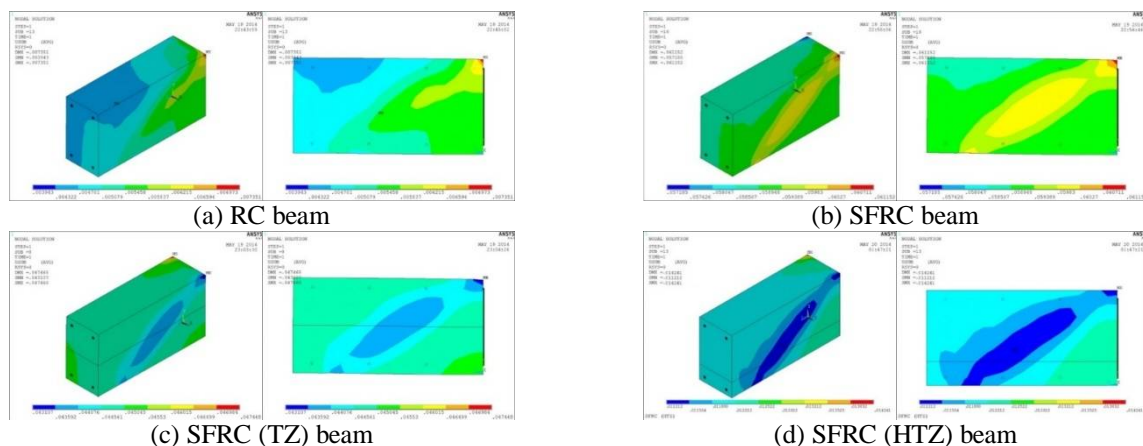


Fig. 17: Maximum displacement

Both experimental and finite element analysis results showed that the SFRC beam sustained highest stress and maximum deflection during compression. The crack pattern for both SFRC (TZ) beam and SFRC beam is similar, proving that the steel fibre content in the conventional concrete do increases the concrete matrixes bonding, thus reduces the crack propagation and maximum deflection magnitude.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

V. CONCLUSION

Based on this research study, it can be concluded that when the reinforced concrete beam subjected to flexural load, the addition of 1.0% steel fibre in reinforced concrete beam has increased the ultimate load, improved deflection and reduced crack. The presence of steel fibre in concrete matrix also can provide better performance in carrying high stress compare to steel fibrous reinforced concrete (tension zone) beam, steel fibrous reinforced concrete (half tension zone) beam and reinforced concrete beam. To be conclude in terms of crack propagation and economy, steel fibrous reinforced concrete (tension zone) beam is a most suitable option to incorporate steel fibre in conventional reinforced concrete beam. The flexural strength of steel fibrous reinforced concrete (tension zone) beam is slightly low than flexural strength of steel fibrous reinforced concrete beam, but, the cracks width and cracks pattern is almost similar. To conclude in term of strength of reinforced concrete beam, full steel fibrous reinforced concrete beam is the most effective way to incorporate steel fibre in the conventional reinforced concrete beam because when the 25 kg/m³ (1%) of steel fibre added into the reinforced concrete beam, the steel fibrous reinforced concrete can sustain highest compressive strength and flexural strength compared to plain reinforced concrete beam, steel fibrous reinforced concrete (tension zone) beam, steel fibrous reinforced concrete (half tension zone) beam. It be concluded that finite element was predicted the higher displacement compared to the experiment. Steel fibre content indicated compressive and tensile stresses characteristics. The finite element analysis and experimental results differs slightly in term of stress. SFRC beam can resist highest stress and contained smaller deflection. Compressive cracks propagated primarily parallel to the direction of the compressive applied load, and flexural cracks resulted from the tensile strains developed from Poisson's effect. All beams failed under flexural cracks. SFRC (TZ) is an economical solution to inhibit flexural cracks.

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