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MODELING OF STEEL FIBRES AS FLEXURAL CRACKS INHIBITOR IN REINFORCED CONCRETE BEAM

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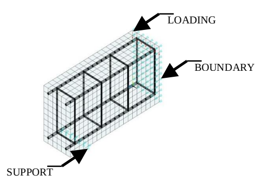
Graphical abstract



Abstract

Flexural cracks are most common problem on structural members which are subjected to bending moments. 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 25 kg/m³ steel fibre content placement in the beam. The results showed stress patterns from ANSYS software are similar to the experimental findings with minimal magnitude difference of about 11 %. It is concluded that the steel fibre inhibits flexural cracks and delayed the flexural failure in beams as depicted in the experimental results from 11 beams.

Keywords: Modeling, steel fibre, flexural cracks INHIBITOR, reinforced concrete beam

1.0 INTRODUCTION

Whenever tension occurs in concrete beam, cracking will subsequently take place and becomes the fundamental weakness of concrete. Flexural cracks are most common problem and occur when the stresses in the tension zone exceeded the bending strength of concrete. Primary cracks formed and followed by secondary cracks as when bending moment increased. Practically, cracks extend its propagations from the tension face into the zero stress location of the beam cross section. Crack widths will always be the greatest at the tension face. The introduction of steel fibre in concrete beam has been proposed as flexural cracks inhibitor. In this study, ANSYS was used to compare the finite element analysis with the three-point bending experimental test results.

2.0 FINDINGS FROM PREVIOUS RESEARCH

Padmarajaiah and Ramaswamy [1] conducted a three-dimensional nonlinear finite element analysis by using ANSYS 5.5. The mesh consisted of one concrete element along the length, eight elements over the depth and three elements across the width. The finite element solution was in close agreement on the load deformation characteristics compared to the experimental results. Padmarajaiah and Ramaswamy [1] concluded that the crack patterns at both initial and at failure stages predicted by finite element analysis indicated that the effect of fibres on the concrete strength and ductility and its bridging effects in arresting crack propagation have been suitably captured. Özcan *et al.* [2] tested Steel Fibre Reinforced Concrete (SFRC) beams in laboratory under four-point bending test and finite element solutions were obtained by using ANSYS 14.5. They used eight node solid brick elements (Solid35) to model concrete and 3D spar elements (Link8) for reinforcement bar. Each concrete mesh element is a prism with cubic size of 25 mm. They obtained that the deflections and stresses at the centerline along with initial progressive cracking of the finite element model compared well to experimental data obtained from the reinforced concrete (RC) beam and the failure load predicted is very close to the failure load measured during experiment. Marta Słowik and Tomasz Nowicki [3] compared experiment test results with numerical results made on the Finite Element Method, ABAQUS 6.6. The numerical simulations showed the differences in maximum stress distribution according to shear span to depth ratio (a/d). The ratio is the primary parameter that significantly affects the shear failure mechanism in flexural concrete members with longitudinal reinforcement but without transverse reinforcement [3]. The numerical analysis results are promising. These findings deduced that significant comparison can be made between experimental and modeling in ascertaining the stresses, displacement and crack propagation. Mohd Yuasrizam Musa *et al.* [4,5] conducted only experimental researches on crack assessment of steel fibre reinforced concrete beams.

3.0 METHODOLOGY

ANSYS is a large scale, general purpose, finite element computer aided engineering software used to simulate and solve a wide variety of problems from wide variety physics environments [6]. 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.

3.1 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, E_X is the modulus of elasticity of the concrete (E_c) and PR_{XY} is the Poisson's ratio (υ). 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/mm^2, 48.335 N/mm^2 and 200 N/mm^2 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/mm^2 and 0.3 respectively.

3.2 Geometry

The full size dimension of the beams is 150 mm × 250 mm × 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 modeled as shown in Figure 1 giving the modeled volume of 150 mm × 250 mm × 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.

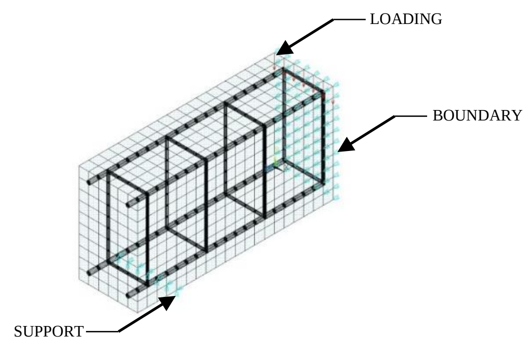


Figure 1 Beam model

3.3 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 mm × 25 mm × 25 mm. The necessary element division was noted. The reinforcement requires no specific meshing as individual element was created using nodes.

4.0 RESULTS AND DISCUSSION

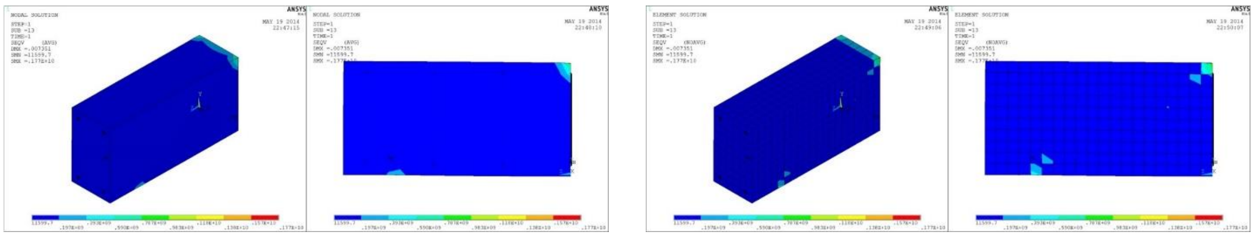
In this study, beams were modeled as RC, SFRC, SFRC (TZ) and SFRC (HTZ). The differentiation was made according to the placement of steel fibre content within the beams. Inclusion of steel fibre is analysed to give optimal results of stresses, displacement and crack propagations.

4.1 Stresses and Displacement

The maximum stress (MN for maximum tensile stress and MX for maximum compressive stress) for the last converged load for nodal solution and element solution step is shown in Figure 2 with the magnitudes shown in Table 1.

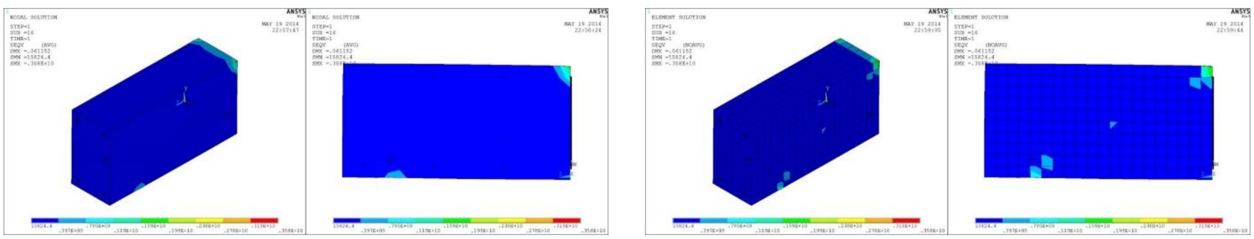
According to the finite element analysis, the compressive stress and tensile stress is increase according to higher steel fibre portion as shown in SFRC beams recording 35.8 N/mm^2. Similar trend is seen in the experimental results. Magnitudes from the numerical modelling are optimistic over the experimental 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 1 and Figure 3.

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.



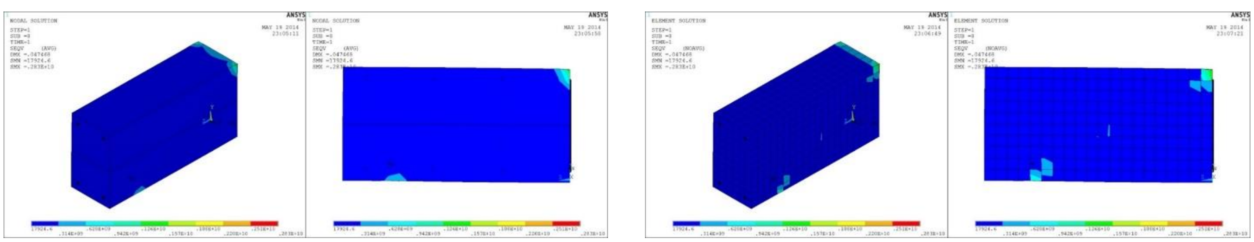
(i) Nodal solution (ii) Element solution

(a) RC beam



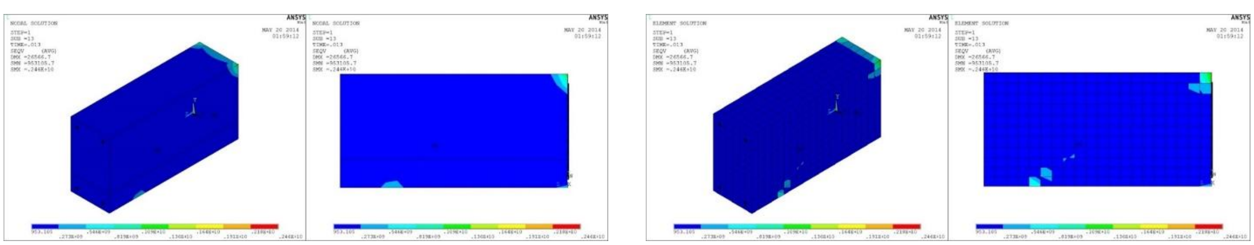
(i) Nodal solution (ii) Element solution

(b) SFRC beam



(i) Nodal solution (ii) Element solution

(c) SFRC (TZ) beam



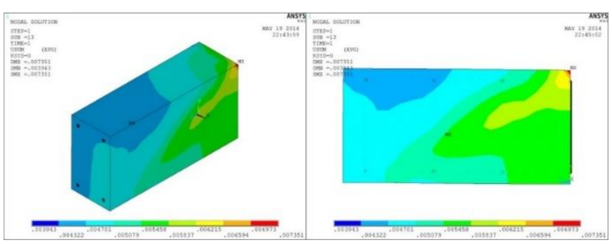
(i) Nodal solution (ii) Element solution

(d) SFRC (HTZ) beam

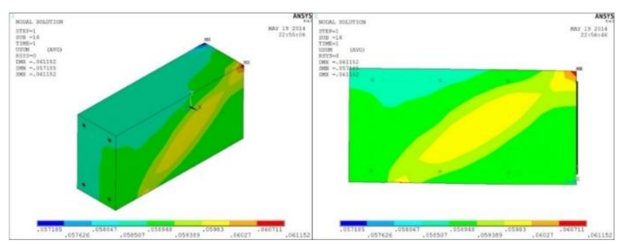
Figure 2 Maximum compressive stress and tensile stress

Table 1 Maximum stresses

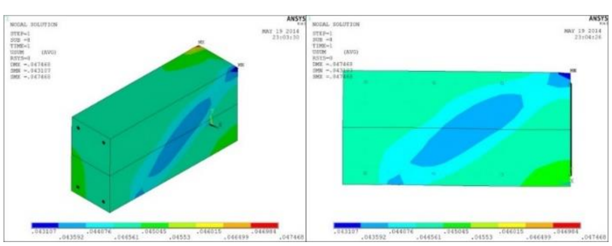
Sample	Experiment		Finite Element Analysis					Experiment vs Finite Element Analysis	
			Stress						
			Nodal Solution		Element Solution				
	Ultimate Flexural Stress [N/mm²]	Maximum Displacement [mm]	Compressive Stress [N/mm²]	Tensile Stress [N/mm²]	Compressive Stress [N/mm²]	Tensile Stress [N/mm²]	Maximum Displacement [mm]	Stress [%]	Maximum Displacement [%]
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						28	147
SFRC Beam 2	28.63	13.88	35.8	0.00016	35.8	0.00016	61.152	22	126
SFRC Beam 3	27.83	16.01						25	117
SFRC (TZ) Beam 1	21.43	12.88						28	114
SFRC (TZ) Beam 2	22.23	11.44	28.3	0.00018	28.3	0.00018	47.468	24	122
SFRC (TZ) Beam 3	22.23	9.12						24	136
SFRC (HTZ) Beam 1	15.03	9.93						48	36
SFRC (HTZ) Beam 2	15.03	12.75	24.6	0.009	24.6	0.009	14.241	48	11
SFRC (HTZ) Beam 3	14.23	10.25						53	33



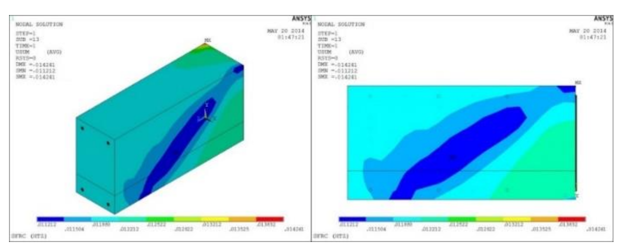
(a) RC beam



(b) SFRC beam

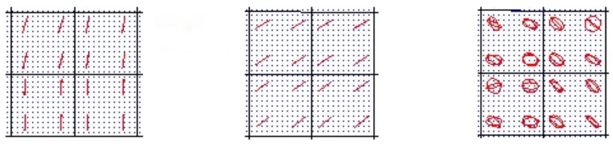


(c) SFRC (TZ) beam



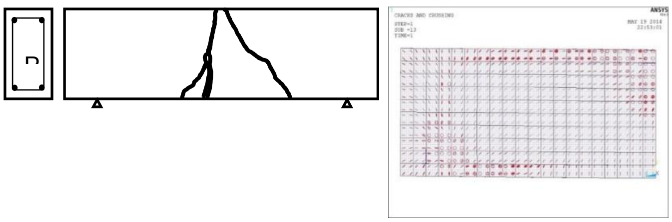
(d) SFRC (HTZ) beam

Figure 3 Maximum displacement

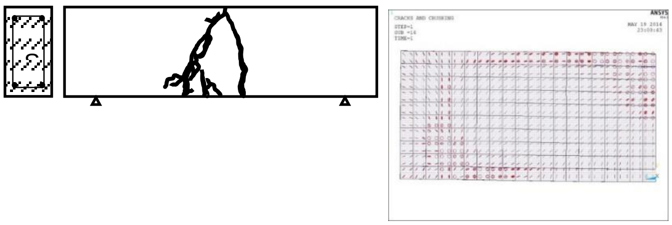


(a) (b) (c)

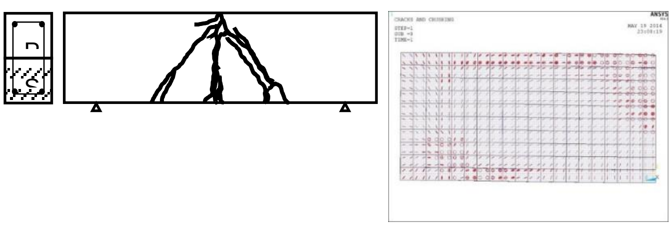
Figure 4 Cracking signs



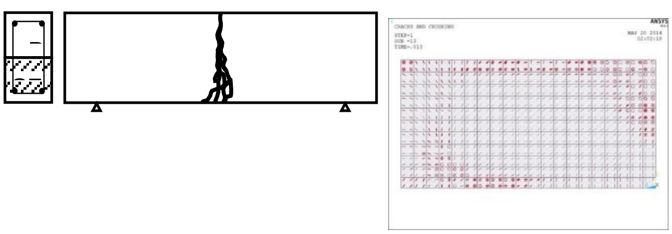
(a) RC beam



(b) SFRC beam



(c) SFRC (TZ) beam



(d) SFRC (HTZ) beam

Figure 5 Cracks and crushing

4.2 Cracks

The crack patterns captured through finite element analysis is shown in Figure 4. They are classified as (a) flexural cracks, (b) diagonal cracks and (c) compressive cracks. Figure 5 depicted the cracks and crushing plots of the beams.

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

5.0 CONCLUSION

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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