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Simulation Investigation on Reinforced Concrete by Carbon Fiber Reinforced Polymer

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In this study, we present a static finite element study of reinforced concrete beam reinforced by steel fibers subjected to a load of 500 kN. Preliminary results in term of simulation using a code-program (Abaqus) are presented. The use of reinforced fiber in civil engineering is increasing rapidly and various type of fiber is used such as glass, carbon and steel. The material model was simulated in Abaqus finite element package and is capable of developing the stress-strain curves. The beam was loaded in three-points. The mechanical properties of the steel and the concrete used in our simulation were obtained from the data of the literature. The results obtained in terms of constraints and displacements are discussed. By this study, we intend to contribute to a better understanding stress-strain by using steel fiber as reinforcement in concrete beam. By this work, we contribute to more understanding of the component of stress and strain law using an experimental study that was further verified by a numerical study to eventually predict to what extent a reinforced concrete structure can resist in the elastic mode.

Keywords: Steel fibers, concrete beam, finite element, stress, strain, strengthening.

1 INTRODUCTION

1.1 Research Background

When a beam is not sufficiently reinforced to resist load, many phenomena takes place such as mixed-mode cracks [1-5]. Thus, the application of reinforcement has received much attention in the construction engineering indus-

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*Corresponding author's e-mail: m.aitelfqih@gmail.com try. In the other hand, reinforced concrete can be modeled within finite element. It should be able to representing both elastic and inelastic behavior of concrete in flexion. Many investigation research studies on strengthening of RC beams with FRP composites have been conducted [6-10]. However, recent findings have highlighted major influential parameters related to shear strengthening with externally-bonded (EB) FRP that have still not been captured by current predictive models, including standard codes and guidelines Mofidi et al. [11]. The objectives was according to this authors to investigate experimentally and analytically the effect of the influential parameters which have been found to affect the shear resistance of EB FRP; and to propose a set of transparent, rational, and evolutionary design equations to calculate the shear contribution of EB FRP to the shear resistance of strengthened RC beams.

1.2 Outline of previous work

The results of an experimental investigation on reinforced concrete (RC) T-beams retrofitted in shear with prefabricated L-shaped carbon fiber–reinforced polymer (CFRP) plates were presented by Mofidi et al. [12]. They show that the performance of the specimens strengthened with partially and fully embedded L-shaped CFRP plates in the beam flange was superior to that of the beams strengthened with EB FRP sheets and L-shaped CFRP plates with no embedment. Rena et al. [13] studied one of the most devastating failure models in reinforced concrete structures i.e. the diagonal tension failure. Numerical model was used capable of dealing with both static and dynamic crack propagation.

1.3 Research Rationale

This work presents a finite-element (FE) study by Abaqus code simulation of a reinforced concrete by steel fibers subjected to flexion at a point in the middle with 500 kN. This beam rests on two movable supports. In the first one the displacement is fixed along the Y axis ($U_2 = 0$), and in the second, the displacement is fixed along the X axis and the Y axis ($U_1 = 0$ and $U_2 = 0$). All the mechanical properties of the steel and the concrete used in our simulation are obtained from the data of the literature.

2 MATERIALS DETAILS AND SIMULATION PROCEDURES

2.1 Materials details

The FE model of reinforced concrete beam consists of two types of materials, concrete and steel fiber. The beam cross section was reported in Figure1. The reinforced layer by steel fiber is embedded within the concrete element using embedding technique available in Abaqus.

The mechanical properties of concrete and steel used in the simulation were presented in table 1. It's the material parameters that are fed to then numerical model.

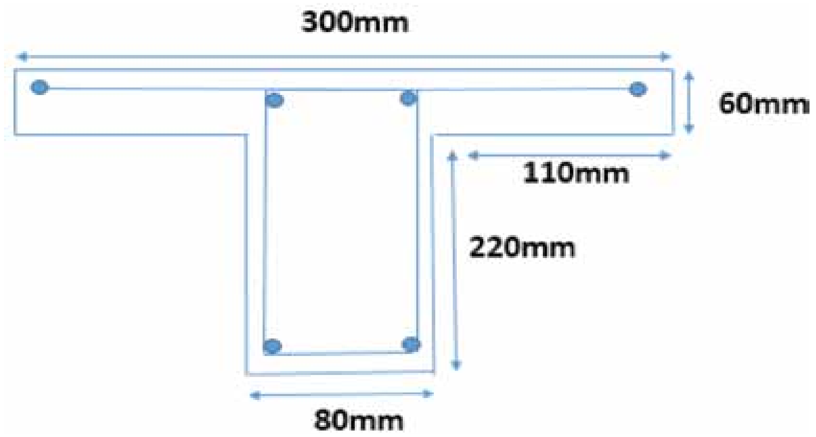

FIGURE 1
Cross-section of the beam.

TABLE 1
Mechanical properties of concrete and steel.

Concrete	
Density	$\rho = 2400 kg / m^3$
Young's modulus	$E = 29.5\ N / m^2$
Poisson's ratio	$\vartheta = 0.2$
Dilatation angle	30
Eccentricity	0.1
Compressive strength	$f_c = 2.4.10^7\ N / m^2$
Tensile strength	$f_t = 2.4.10^6\ N / m^2$
Steel	
Density	$\rho = 7850\ kg / m^3$
Young's modulus	$E = 1.9.10^{11}\ N / m^2$
Poisson's ratio	$\vartheta = 0.3$
Yield stress	$f_y = 2.1.10^8\ N / m^2$

2.2 Simulation Procedures

Numerical tests were carried out using the well tested commercial finite element Abaqus software (CAE 6.13-1). It's provides the capability of simulating the damage using either of the three crack models for reinforced concrete elements: (1) Smeared crack concrete model, (2) Brittle crack concrete model, and (3) Concrete damaged plasticity model. Out of the three concrete crack models, the concrete damaged plasticity model is selected in the present study as this technique has the potential to represent complete inelastic behavior of concrete both in tension and compression including damage characteristics. Further, this is the only model which can be used both in ABAQUS/ Standard and ABAQUS/Explicit and thus, enable the transfer of results between the two. Therefore, development of a proper damage simulation model using the concrete damaged plasticity model will be useful for the analysis of reinforced concrete structures under any loading combinations including both static and dynamic loading [14-15]. The beam is meshed with approximate element size with 50 mm X 50 mm X 50 mm in longitudinal, transverse and thickness direction respectively. For steel fiber, the approximate element size was 26 mm X 26 mm X 26 mm. Mesh convergence study carried out using displacement measurements depicts that the above mesh is finer enough to obtain a reliable result.

The normal stress σ_{max} at a point M with across-section S is given by the relation:

$$\sigma_{max} = \frac{M.Y}{I} \tag{1}$$

were M is the resisting moment of the section, Y distance from the neutral surface and I isquadratic moment [16].

The finite element method (FEM) is applied widely in the calculation of structures with reliable results [17-18]. The FEM makes it possible to solve in a discrete manner a partial differential equation whose approximate solution is “sufficiently” reliable. For a linear elastic static problem in one dimension, the governing equation, which is a PDE, is:

$$\frac{d}{dx}[E(x)A(x)du(x)/dx] + b(x)A(x) = 0 \tag{2}$$

where E is the Young’s Modulus, A is the area, u is the displacement and b is the loading. For a linear elastic static problem this is in the format

$$F = K * U \tag{3}$$

where F is the force vector, K is the stiffness matrix, and U is the displacement vector. Solving this gives an approximate (discretized) solution to the governing equation [19-20]. In general, this partial differential equation relates to an approx-

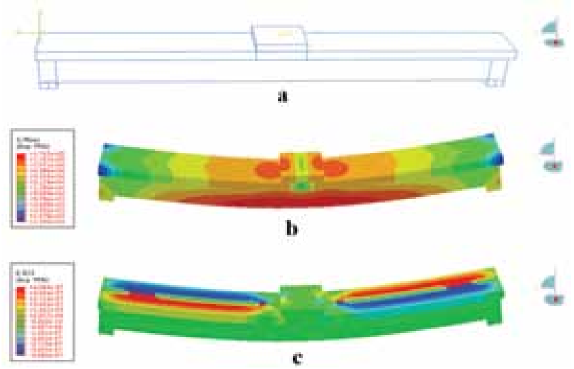

FIGURE 2
Abaqus screen-shots of the model shwoing beam not reinforced assembly in (a); the (b) stress of beam not reinforced; and (c) the strainof beam not reinforced.

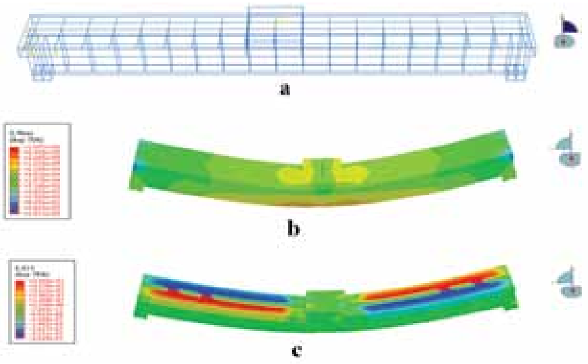

FIGURE 3
Abaqus screen-shots of the model showing beam not reinforced assembly in (a); the (b) stress of beam not reinforced; and (c) the strain of beam not reinforced.

imation function u (x) defined on a domain j_x (x). It contains boundary conditions to ensure the existence and uniqueness of a solution. In this study, the linear 3D element 4 points of integration, an 8-node linear brick, reduced integration, hourglass control (C3D8R) are used for the concrete model. The bar element T3D2 is used when it is for the reinforcement of steel.Moreover, the armatures of the numerical model are simplified and present only axial forces.

3 RESULTS AND DISCUSSION

The numerical results on beam loaded in three-points in the absence and in the presence on reinforced by steel fibers are presented in Figure 2 (a) and

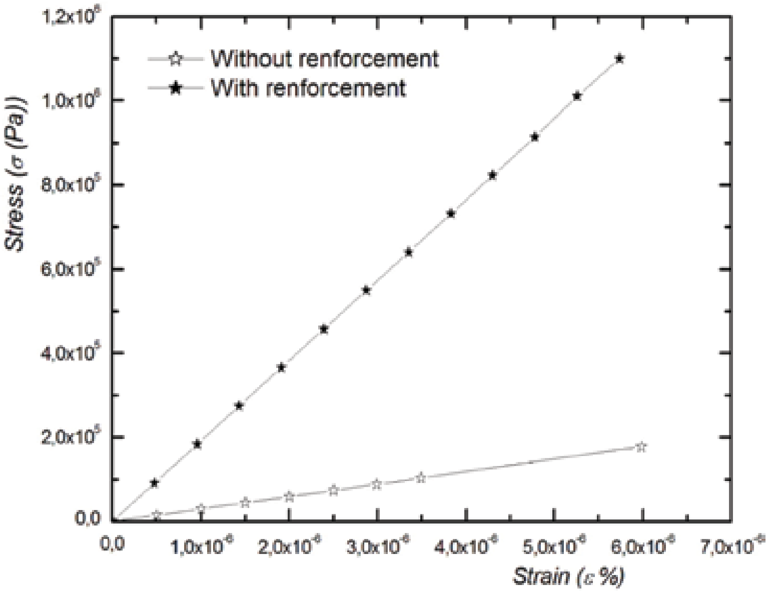

FIGURE 4
Stress–strain curve of concrete in the presence and in the absence of reinforcement.

Figure 3 (a) respectively. The load was about of 500 kN. Figure 2 (b) and Figure 3 (b) give the stress, and Figure 2 (c) and Figure 3 (c) the strain. The comparison of FEM results on flexing shows that the reinforced beam resists sharp stresses and can reach up to a factor of 6.

Rajendra and Mogre [21], conclude that, the replacement of natural sand with artificial and is fissile and behavior and strength of reinforced concrete will be improved. Also, the use of polypropylene fibre will enhance strength and behavior of reinforced concrete also improves resistance against impact loading and fire. Polypropylene fibers have a positive impact on ultimate strength of heated beams. For a heating duration of 4.5 hours, the residual ultimate strength is larger than the corresponding strength of beams without polypropylene fibers by more than 60 %. No sudden failures are observed in all beams containing polypropylene fibers. Mofidi et al. [22] investigated that PFRC does provide improved impact resistance with increasing volumes of fibers. A PFRC mixture does provide reductions in permeability provided that the water-cement ratio remains below 0.5. Increased percentages of fibers further decreased the permeability provided the mixture remained workable. The study indicates a reduction in plastics shrinkage with increasing amounts of fibers. The polypropylene fibers decrease plastic shrinkage provided the water-cement ratio remains below 0.5. Wear resistance of PFRC has not been widely studied, but one study found an increase in the wear resistance with increasing fiber contents.

In order to elucidate this exaltation, we plot the stress-strain curve of concrete in the presence and in the absence of reinforcement (Figure 3). Linear stress-strain relationships which obey Hooke's law is assumed up to 50% of the ultimate compressive strength (σ_{cu}) in the ascending portion.

Moreover, the complete stress-strain curve for concrete under compression is derived using the experimentally verified numerical method by Hsu et al. [23]. This model can be used to develop the stress-strain relationship under uni-axial compression. This numerical model is used only to calculate the compressive stress values (σ_c) between the yield point (at 0.5 σ_{cu}) and the 0.3 σ_{cu} in the descending portion using:

$$\sigma_c = \left(\frac{\beta(\epsilon_c / \epsilon_o)}{\beta - 1 + (\epsilon_c / \epsilon_o)^{\beta}} \right) \sigma_{cu} \tag{4}$$

where, the parameter β which depends on the shape of the stressstrain diagram is derived from:

$$\beta = \frac{1}{1 + (\sigma_{cu} / \epsilon_o E_0)} \tag{5}$$

and the strain at peak stress ε_0 isgiven by:

$$\epsilon_o = 8.9x10^{-5}\sigma_{cu} + 2.11x10^{-3} \tag{6}$$

Figure 3 presents stress versus strain curves in linear mode for beams strengthened and un-strengthened with fiber steel. The mechanical properties of concrete and steel used in the simulation sere presented in table 1. It's the material parameters that are fed to the numerical model. The maximum stress of reinforced beam is located at 1.1 MPa and for beam without reinforcement at 0.17 MPa. The maximum strain is attained at the same point for each beam. Strengthened beam had a slope of line more pronounced then the un-strengthened one. A similar phenomenon was experimentally observed by Mofidi *et. al.* [12] with beam strengthened by fiber-reinforced polymer. Moreover, the shear results show that reinforcement of the beam is not obtained.

In the other hand, different forms simulation models presented in the literature as reviewed in the paper by Nayal *et. al.* [24]. The model developed was used in the study of Wahalathanri *et. al.* [15] and it was applicable for both reinforced and fibre reinforced concrete with only minor changes. Also, this method indicates similarity to the tension stiffening model that is needed for ABAQUS concrete damaged plasticity model. This tension stiffening model was originally based on the homogenized stress-strain relationship developed by Gilbert et al [25] which accounts for tension stiffening, tension softening and local bond slip effects. Two descending portions of the tensile stress strain graph has accurately captured the response caused by primary and secondary cracking phenomena. The layered tension stiffening parameters used is replaced with a single set of stiffening parameters applicable to the entire tensile zone by the Nayal *et. al.* [24].

Experimental analysis was done with addition of steel fibers by Hannant *et. al.* [25]. They found that the addition of steel fibers has more influence on the flexural strength of concrete compared to its tensile/compressive strength. As reported by Oh et al. [26], the flexural strength of SFRC has been increased about 55% with the addition of 2% by volume of steel fibers. Johnston [27, 28] has found that the compressive strength of SFRC is increased about20% with the addition of 1.2% by volume of steel fibers. Research conducted by Johnston [29] showed that the compressive strength of SFRC has been increased from 0 to 15% with the addition of up to 1.5% of steel fibers by volume. In a research conducted by Hartman [30] twelve different SFRC beams containing two different SFs amount of 60 and 100 kg/m3 of Dramix RC- 65/35-BN type were tested and it was concluded that the ratio of the experimental ultimate load to the theoretical ultimate load was bigger for those SFRC beams having a 60 kg/m3 amount of SFs. Narayanan and Darwish [31] reported that the mode of failure has changed from shear to flexure when the percentage of steel fibers was increased beyond 1.0%. According to the results of Behbahani *et al.* [32], the cube compressive strength test, it is observed that the cube compressive strength of specimens made from C30 and C50 classes of concrete with addition of 1.0% by volume of the SF has increased appreciably compared to other specimens with different percentage of steel fibers. Based on the results of flexural strength test, it is concluded that both the first cracking strength and flexural toughness of prisms made from C30 and C50 classes of concrete with addition of 1.0% by volume of the SFs has increased considerably as compared to those prisms with different percentage of the SFs. Therefore, it can be concluded that in SFARC beams made from concrete grade of 30 MPa and 50 MPa, the optimum percentage of the hooked-end SFs with the dimensions of 0.75 mm in diameter and 50 mm in length is 1.0% by volume with respect to cube compressive strength and flexural toughness and first cracking strength tests.

4 CONCLUSIONS

The study of strengthened and un-strengthened beam by FEA was conducted using ABAQUS code. The results showed that reinforcement was better with flexion. Factor of 6 was obtained in the presence of steel reinforcement. It is therefore proposed that further study is to be conducted on shear behavior and the failure modes of reinforced beams with fiber reinforced polymer sheets.

Also, it is envisaged to improve the database on shear reinforcement and then validate the approach of the model proposed in the literature.

Nomenclature

E	Young's modulus (N/m^2)
f_c	Compressive strength (N/m^2)
f_y	Yield stress (N/m^2)
f_t	Tensile strength (N/m^2)
$\acute{o}_{max}$	Normal stress (N/m^2)
S	Cross-section (N/m^2)
M	Resisting moment of the section (N.m)
I	Quadratic moment (m^4)
A	Area (m^2)
u	Displacement (mm)
b	Loading (N)
F	Force vector
K	Stiffness matrix
U	Displacement vector
σ_{cu}	Compressive strength

Greek symbols

È	Poisson's ratio
ρ	Density of workpiece material (kg/m3)
ε_0	Strain at peak stress

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