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Experimental and Analytical Study on Pull-out Force of Steel Fiber-Reinforced Concrete Blocks

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ABSTRACT

Reinforcing bar bonding in concrete is essential for reinforcing bar anchoring and reinforced concrete cracking control. A pull-out test of a reinforcing bar embedded in a concrete block is commonly used to determine it. When compared to plain concrete, steel fiber enhanced the mechanical properties of reinforced concrete. This paper presents experimental and analytical study on pull-out force of steel fiber-reinforced concrete blocks. Experimental program consists of six specimens. Two parameters are considered in this study, which are steel bar diameter and content of steel fiber. The analytical analysis was carried out by the finite element ANSYS program and was performed on the experimental specimens. An analytical analysis was conducted to investigate the developing of the shear stress in surrounding concrete in XZ-plan and stresses in steel bar. Test results show that the steel fiber has important effect on the increase of the pull-out force. The pull-out force for specimen with 16 mm steel bar increased by 15% when use the steel fiber compared with specimen without steel fiber.

1. Introduction

The bonding of reinforcement bars has an important role to play in the Reinforced Concrete (RC) behaviour [1]. Insufficient bonding may result in excessive slipping of the reinforcement bars, resulting in ineffective anchoring of the reinforcement bars and severe the RC cracking [2]. In addition, the fibers adding might improve the bonding of reinforcement bars and improve some other characteristics of RC [3]. Generally, the bonding of reinforcement bars in concrete is necessary in areas subject to shearing and concentration of stress such as narrow stitches in bridges, concentrated load bearings and beam column joints in buildings [4–7]. The strength of bond for the reinforcing bars during the final strength process must also be taken into account.

The bonding reinforcement bar are import for control of crack during durability and serviceability. First, the width of crack is associated to the reinforcement bar bond-slip on a crack, as it is literally equal to the amount of the bond-slip on the crack both sides [8]. Second, the cracking mechanism may be slowed or even altered by strengthening the concrete-to-reinforcement-bar bond in order to prevent cracking [9].

The use of various kinds of steel fibers to change the plain concrete to RC has been a successful means of strengthening the bonding of reinforcement bars [3, 10, 11]. The fiber-RC has been shown to be efficient in improving the concrete mechanical properties [12] and improving the resistance to shock vibrations and earthquake resistance of the RC structures [13,14] in addition to achieving better bonding between reinforcement and the RC and

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enhancing crack controls. Some applications are becoming more involved. Steel fiber is improved the mechanical characteristics of RC, such as ductility, flexural and tensile strength. Remarkable improvements in tension strength were achieved when using steel fiber because of the fibers effecting in crack arresting [15-19].

The effect of strand surface in efficiency of bond are examined by Rose [20]. The authors carrying out pull-out tests on non-tension and tension strands, and stated that tensioned strands tests are challenging to conduct and provided conflicting results for bonding strength of the strands.

Girgis [21] carried out a pull-out test on non-tensioned pre-stressing strands of large blocks and prisms of self-consolidated concrete. The pull-out loads have been applied to specimens using two techniques.

Chao et al. [22] tested the bonding strength of non-tension threads embedded in prisms reinforced by different fiber types. Fibers added to the 1 percent volume fraction of a concrete matrix were found improving the strands concrete bond. They found the pull-out behaviour of the tension strands was improved by minimizing the width of cracks in concrete prisms.

Krahl et al. [23] preformed a pullout tests in ultra-high-performance fiber RC at different ages with 0°, 30°, and 45° embedment angles fibers. They found that bond strength increases in average of 2.9, 4.5, and 3.9 for fiber angles of 0°, 30°, and 45°, from 1 to 28 days.

In this study, experimental and analytical work was presented to study the bonding behaviour of steel bar embedded in steel fiber-RC blocks. Experimental program consists of six specimens. Two parameters are considered in this study, which are steel bar diameter and content of steel fiber. The specimens are tested until the failure has occurred. There is a gap in analytical investigations on the pull-out behaviour. Therefore, a FE ANSYS program was used to perform the analytical analysis and was carried out on the experimental specimens. An analytical analysis was carried out to study the developing of shear stress concrete and stresses in bar.

2. Experimental program

Experiment program consists of six reinforced specimens. The specimen's dimensions are 15*15*15 cm as shown in Figure 1. In this study, steel bars with 10 mm, 12 mm, and 16 mm diameters are considered. The details of specimens considered in this study are listed in Table 1.

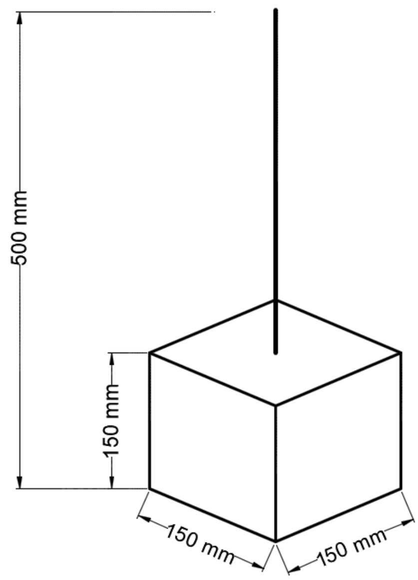


Figure 1. Dimension of specimens

Table 1: Details of specimens

Group	Specimen	Steel bar Diameter (mm)	Steel fiber content by volume (%)
A	C1	10	—
	C2	12	—
	C3	16	—
B	CS1	10	0.5
	CS2	12	0.5
	CS3	16	0.5

The concrete mix percentage that was developed and used was 1:2:2.3:0.55 (cement: fine aggregate: coarse aggregate: water). Coarse aggregate (crushed gravel with a maximum size of 12 mm) and fine aggregate (fine sand with a size interval of 0-4 mm) were used in the concrete mix design. All types of concrete were made using the same mix with 350 kg/m^3

cement. Cylinders with a 15 cm diameter and a 30 cm height were cast for test of compressive strength. The concrete strength is shown in Table 2.

Table 2: Concrete compressive strength

Concrete type	Compressive strength (MPa)
Normal Concrete	33.30
Concrete with steel fiber	34.10

Detailed properties and the pictures of the steel fiber are presented in Table 3 and Figure 2. The specimens were arranged into two groups. Groups A and B containing steel fiber content ratios equal to 0.0% and 0.5% of the concrete weight, respectively. The pull-out test was performed in accordance with ASTM C 900 – 06 standards.

Table 3: Steel fiber properties

Parameter	Value
Diameter (μm)	750
Tensile strength (MPa)	1200
Length (mm)	30
Modulus of elasticity (GPa)	210
Density (g/cm3)	7.85

Figure 2. Steel fiber used in the study

2.1 Test results and discussion

This section presents and discusses the results of pullout tests performed on specimens, as well as the behavior of specimens for normal concrete and concrete with steel fiber under pull-out tests. The pullout force of the tested specimens are shown in Table 4.

Table 4: Pull-out force

Group	Specimen No.	Pull-out force (kN)
A	C1	56
	C2	57.3
	C3	64.25
B	CS1	58.13
	CS2	59.54
	CS3	75.33

From Figure 3 and Table 4, it be noticed that the pullout force increases with diameter of bar. In comparison to C1, the pull-out force of specimens C2 and C3 has increased by 3% and 12%, respectively, that due to the bond strength of higher bar diameter increase with increasing bar diameter. For the similar degree of confinement, bigger bars have bigger area of contact between the bar and concrete, therefore, that achieve more total bonding strength than smaller bars. In addition, the developed bar size plays an important role in confining transverse strengthening to bond strength. As larger bars size, higher strains and therefore more stress are mobilized and better contained in the transverse reinforcement system.

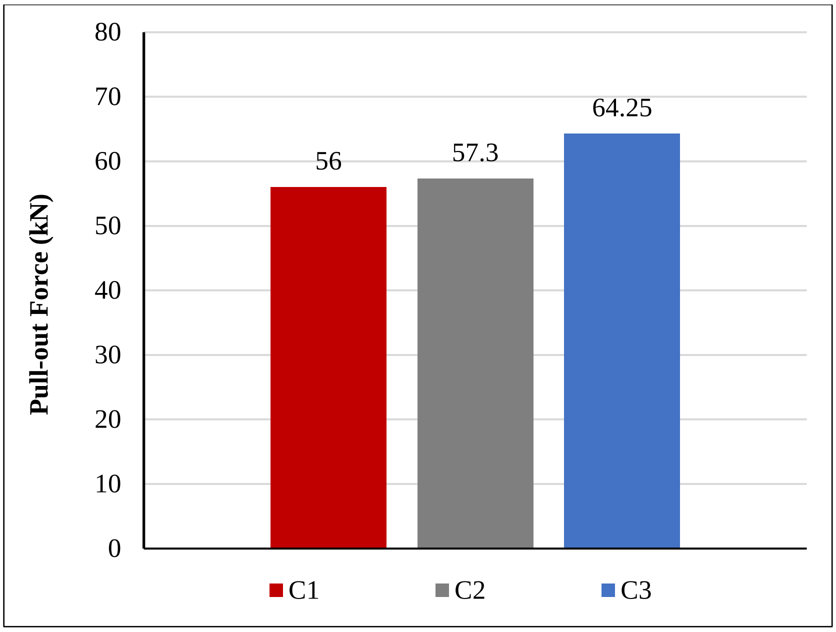


Figure 3. Effect of bar diameter on pull-out force

From Figures 4-6 and Table 4, it can be noticed that the peak pulls out force increased by 4%, 4% and 15% for CS1, CS2 and CS3 respectively compare with specimens without steel fiber C1, C2 and C3. Pull-out mechanisms comprise mainly of the physical and chemical adhesion of straight steel fibers, their debonding and friction resistance.

The presence of fiber increases strength, tensile strength and compressive strength, which are the most important factors influence in bond strength. The efficiency of any reinforced composite depends partly on the bond conditions between a bar or fiber and the matrix; indeed, it is possible, through the interfacial bond, to transmit stress from the matrix to the bar and vice versa.

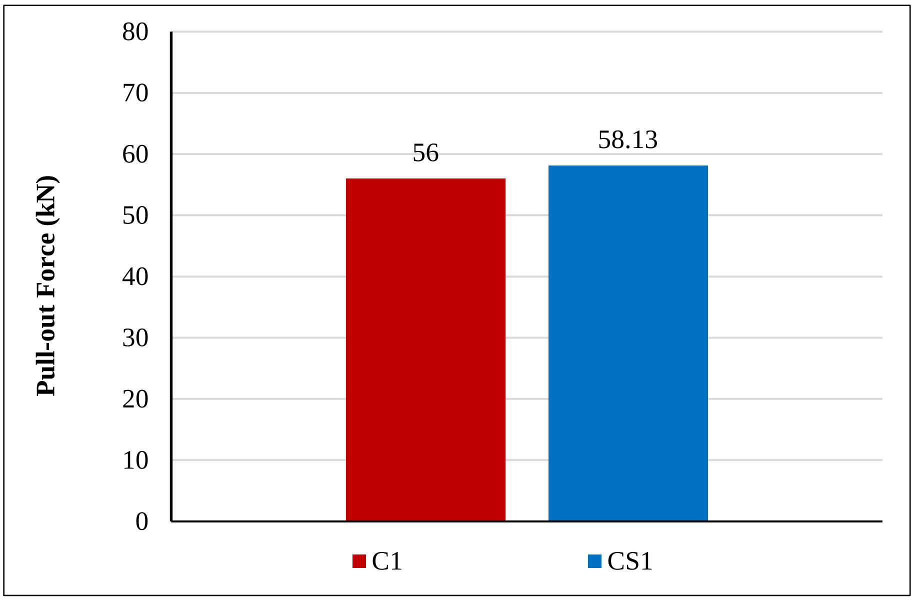


Figure 4. Effect of steel fiber on pull-out force for 10 mm bar diameter

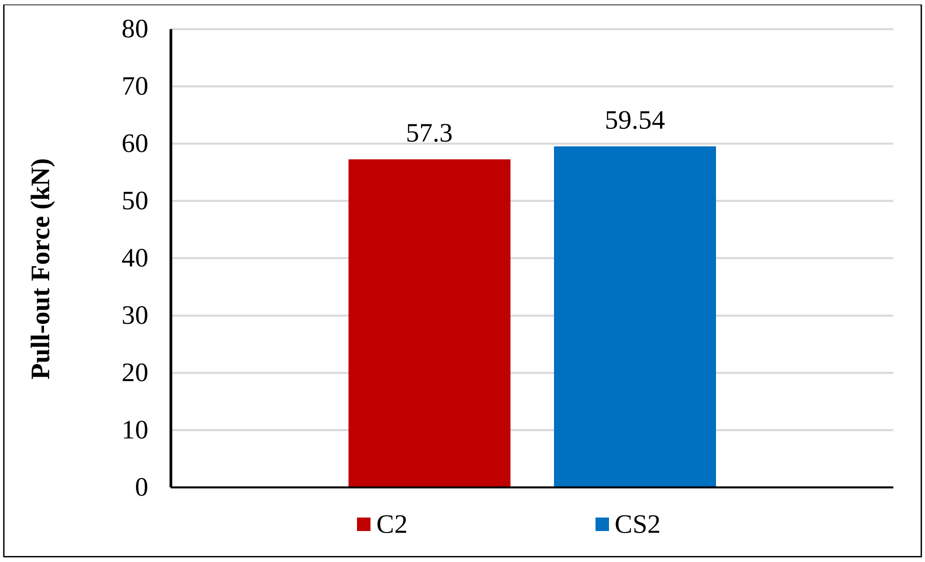


Figure 5. Effect of steel fiber on pull-out force for 12 mm bar diameter

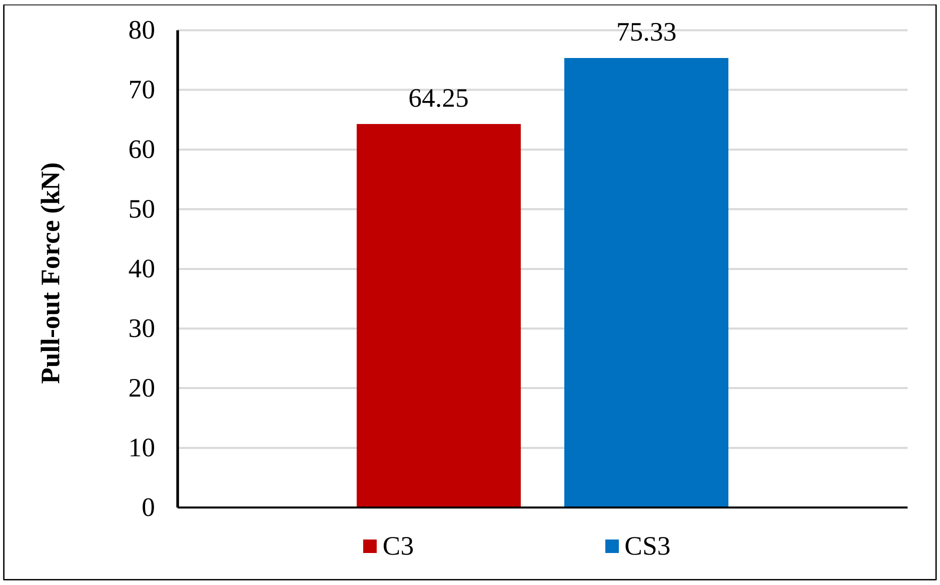


Figure 6. Effect of steel fiber on pull-out force for 16 mm bar diameter

The slip of load end of the bar increased as the load was applied continuously, however there was no slip at the free end. As the load reached the maximum value, slippage at the free end of the bar began and the bar was then pulled-out. At maximum load, the slip of at both the free and load end quickly increased until the free end slip exceeded the limited value as illustrate in Figure 7.

Figure 7. Failure mode

3. Analytical work

The FE ANSYS [24] software was used in this analytical study.

3.1 Finite elements modeling

SOLID65 element has been used to modelling the concrete solids. The element is modelled by 8-nodes and can model the crash in compression and crack in tension.

SOLID45 was used to simulate the reinforcement. Only the axial force is transmitted by this element. For the FE modelling of concrete with steel fiber, the material properties for concrete with steel fiber must adopted.

For the modeling, a 15x15x15 cm cube is used. This research takes into account a perfect connection between steel bar reinforcement and concrete. The length is calculated (Figure 1) using a 500 mm steel bar (including the embedded length). As a first stage in FE analysis, the models were meshed (Figure 8).

The load is applied on the top of the reinforcing steel bar (Figure 9). The model's geometric boundaries are also applied in nodes at the top of cube by fixing it in three directions. On top of the steel bar reinforcement, only Z-direction for displacement is available.

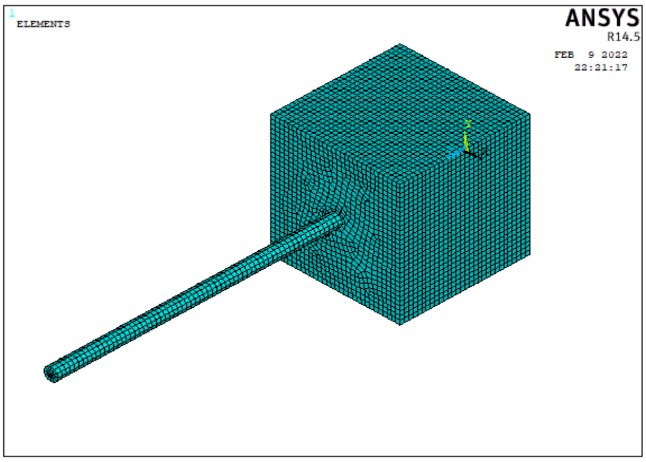


Figure 8. Mesh of FE model

The steel reinforcing bar's elasticity modules, yield stresses and tangent are all specified. In addition, the Poisson's ratio for the bar is defined. The distribution of stress in concrete is mostly determined by the concrete's characteristics rather than the reinforcing steel bar. For steel reinforcement, a yield stress of 400 MPa is considered in this study.

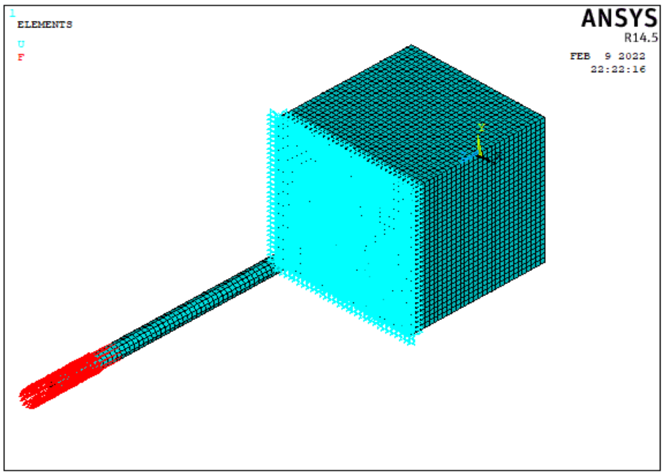


Figure 9. Boundary conditions of FE model

Table 5 listed the material properties of the concrete and reinforcing bars that were considered in the FE analysis. The value of cracking stress was obtained according to ACI 318-11 code.

Table 5: Material properties for reinforcement bar and concrete

Parameter	Concrete	Reinforcement Bar
Modulus of elasticity (MPa)	30000	200000
Diameter (mm)	———	10 or 12 or 16
Yield strength (MPa)	———	400
Poisson′s ratio	0.2	0.3
Crashing stress (MPa)	33.3 or 34.1	———
Cracking stress (MPa)	3.5	———

3.2 Finite elements results

A nonlinear analysis of FEs was used to analyze the specimens. The FE model study is carried out with the ANSYS program [24]. The applied FE method's validity and accuracy are validated. Table 6 summarizes an analytical-experimental comparison based on pull-out load for all specimens.

The experimental and numerical pull-out forces obtained for specimens are listed in Table 6, which shows the good agreement between the experimental and the FE results.

Table 6: FE and experimental pull-out loads

Specimens	Pull-out force (kN)		Error %
	Experimental	FE Analysis	$E = \frac{F.E. - Test}{Test}$
C1	56	54.2	-3.2
C2	57.3	55.3	-3.5
C3	64.25	65.5	2.0
CS1	58.13	60.23	2.1
CS2	59.54	63.67	7.0
CS3	75.33	78.76	4.5

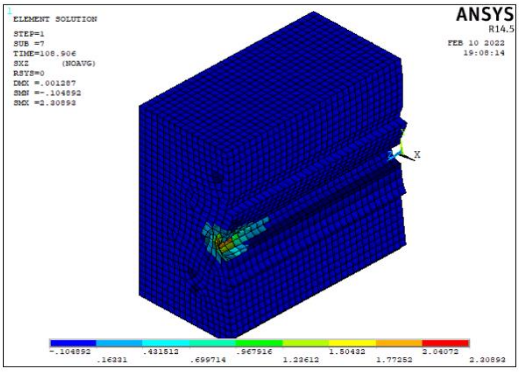
3.3 Analytical study

An analytical study was utilized to investigate the developing of the shear stress in concrete in XZ-plan and stresses in steel bar. A specimen C3 was considered in the parametric study.

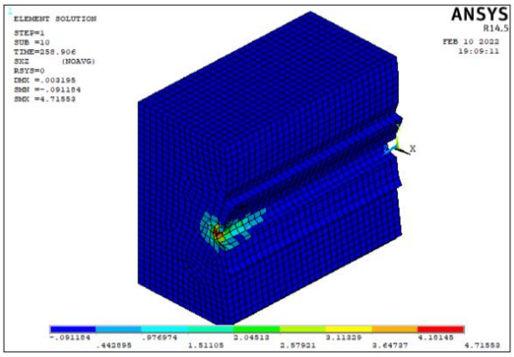
Figure 10 show the XZ-shear stress in concrete for the specimen C3 at different load level. The relationship between shear stress and load was a nonlinear. From this figure, it can be seen that the values of XZ-shear stress depend on the applied load values.

When the model's pull-out load appeared, cracks developed in the surrounding concrete, which spread and grew. At the cube's face, the greatest shear stress values occur.

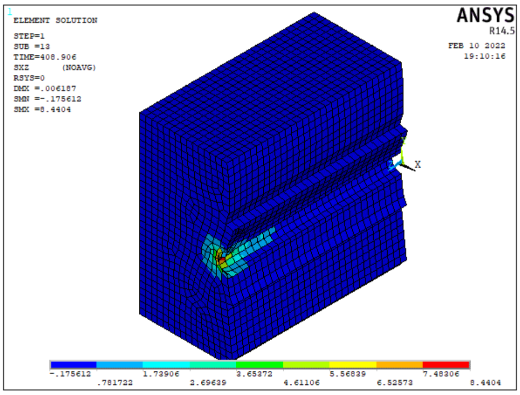
Figure 11 shows the Z-stress in reinforcing steel bar at various load level. It is observed that the tensioning stress value are negligible at end of bar. The Z-stress values begin to increase when shifting from bottom surface to depth.



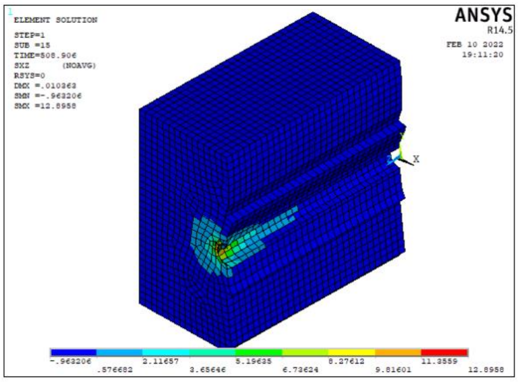
a) at 25% of ultimate load



a) at 50% of ultimate load

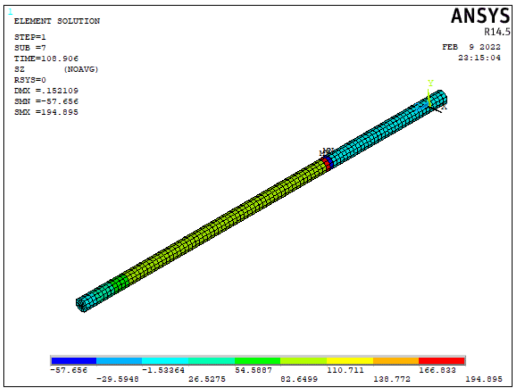


a) at 75% of ultimate load

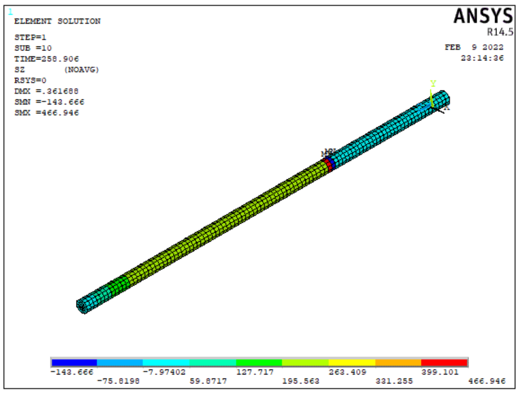


a) at ultimate load

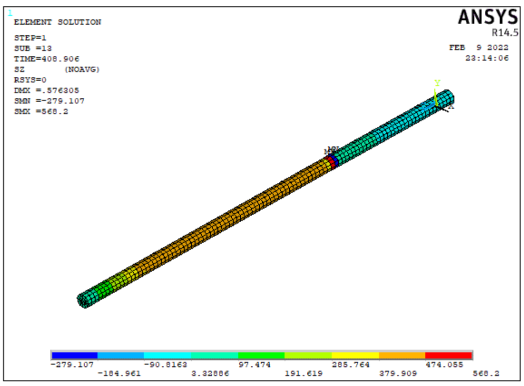
Figure 10. Shear stress in concrete in XZ plane for the specimen C3



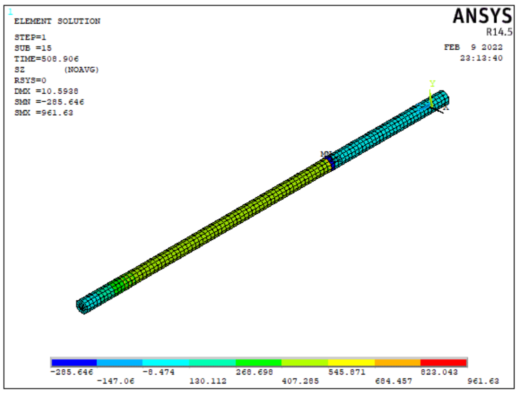
a) at 25% of ultimate load



a) at 50% of ultimate load



a) at 75% of ultimate load



a) at ultimate load

Figure 11. Z- Stress in bar at various load level the specimen C3

4. Conclusions

This paper presents analytical an experimental study of pull-out test on steel fiber-RC blocks. The main objective was studying the effect of steel bar diameter and steel fiber content on the pull-out force. The specimen's dimensions are 150*150*150 mm. A FE ANSYS program was considered to perform the analytical analysis and was carried out on the experimental specimens. Following are the conclusions that can be drawn from the experimental and finite element results of this investigation:

1- The pull-out force increases with bar diameter increase. This represented an increase about 3%, 12% for the bars 12 and 16 mm respectively compared with pull-out force for bar 10 mm.
2- The steel fibers had important effect on the increase of the pullout force. The pullout force increased by 3%, 4% and 15%, for CS1, CS2 and CS3 compared with specimens without steel fiber C1, C2, and C3 respectively.
3- The maximum value of XZ-shear stress appeared at the top part of the cube in the concrete cubes (at H = 0.15).
4- As the value of "H" increases, the Z-stress values in the steel bar begin to increase (moving from surface to depth).

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