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Analytical Study On The Bond Behaviour Between Steel And Concrete Using Comsol.

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ABSTRACT

The load transfer from the steel to concrete in RCC structures are influenced by many parameters. The bond behaviour between steel and concrete are characteristics by steel diameter, concrete strength, embedded length, etc. In this study, the bond strength was found by pull out test, analytically using the software COMSOL. The parameters that are varied in the study are the diameter of the embedded mild steel rod (12 mm, 16 mm & 22 mm), the characteristics strength of concrete (M30, M40 & M50) and the length of the steel which is embedded in concrete (50 mm, 75 mm & 150 mm). The bond strength found using analytical study was compared with the equations proposed by many researchers. The bond strength between embedded steel rod and concrete get decreases by 45% irrespective of change in diameter of the embedded mild steel. Increases in the concrete strength of the cube, increases the bond behaviour of the specimen considerably. In the analytical behaviour variation in the surface temperature of the bottom side of the concrete cube from 300 K to 1000 K, increases the deformation of the specimen and also reduces the distribution of stress in the materials.

Keywords: Bond strength, Comsol, Pull out test, Analytical results, temperature stress

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INTRODUCTION

Ahmed M. Diab.et.al (1), have studied the ultimate bond strength between normal and high strength concrete. The single pull out and double pull out test was conducted by varying concrete strength, water/cement ratios, coarse aggregate types and different cement content. Based on experimental study an equation was arrived to find the ultimate bond strength and required development length. Marco Valente (2), have carried out experimental and analytical study on pull out specimen to investigate the bond behaviour of concrete over embedded steel rods. Ismaeel H.Musa.Albarwary & James H.Haido (3), have studied the bond behaviour of concrete cube with the mild steel reinforcement bars dipped in oil and compared the same with the non-dipped mild steel bars. Md.Rashedul Kabir & Md. Mashfiqul Islam(4), have studied the bond-slip behaviour of the concrete specimens by using finite element software ANSYS 11.0 .Several researches (7-11) proposed many equations to predict the bond strength of the embedded steel and concrete specimens. This paper discusses the bond behaviour of the embedded mild steel bars and concrete cube specimen by analytical study. The parameters that varied are strength of the concrete mix, embedded length of the mild steel reinforcement and diameter of the mild steel rod. The bond behaviour obtained from the analytical results using COMSOL was compared with the proposed equations of many researchers.

ANALYTICAL STUDY

The pull out specimens were modelled using Comsol which is more interactive environment for modelling and simulating scientific and engineering problems. The comsol software were used in many civil engineering applications like, composite materials and construction, fluid mechanics, soil structure interaction, thermal study of the structure etc. Comsol has dedicated physics interfaces for civil engineering applications like structural mechanics. Civil Engineers enable the uses of Comsol to design a simulation tool that ensures users to easily modify the parameters to account for changes in geometry and loads. The steps involved in solving the problem using comsol were given in Figure 1.All pull out specimens were modelled and analysed using Comsol.

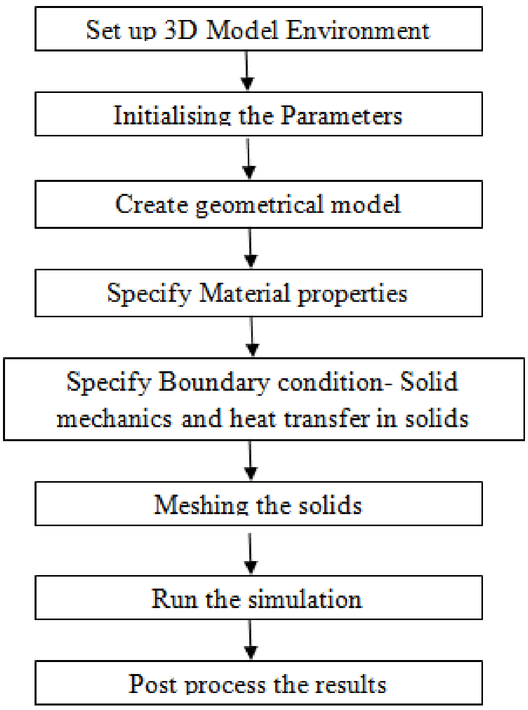

Figure 1: Step by step procedure to solve the problem by COMSOL

RESULTS AND DISCUSSION

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Effect of diameter of the steel bar

The diameters of the mild steel bar varied in the analysis by COMSOL are 12 mm, 16 mm & 22 mm. In the pull out test, the increase in the diameter increases the bond strength by 33 % and 37 % for change in diameter of the embedded steel from 12 mm to 16 mm and from 16 mm to 22 mm respectively. Figure 2 shows the stress distribution diagram of the pull out specimen for varying diameter of the mild steel bar. From the Figure 2, it was observed that the distribution of the stress in the specimen, decreases with increase in the diameter of the embedded steel bar. The percentage decrease in the stress is 42 % for change in the diameter (12 mm to 22 mm), change in the concrete strength (M30 to M50) and change in the embedded length (50 mm to 150 mm).

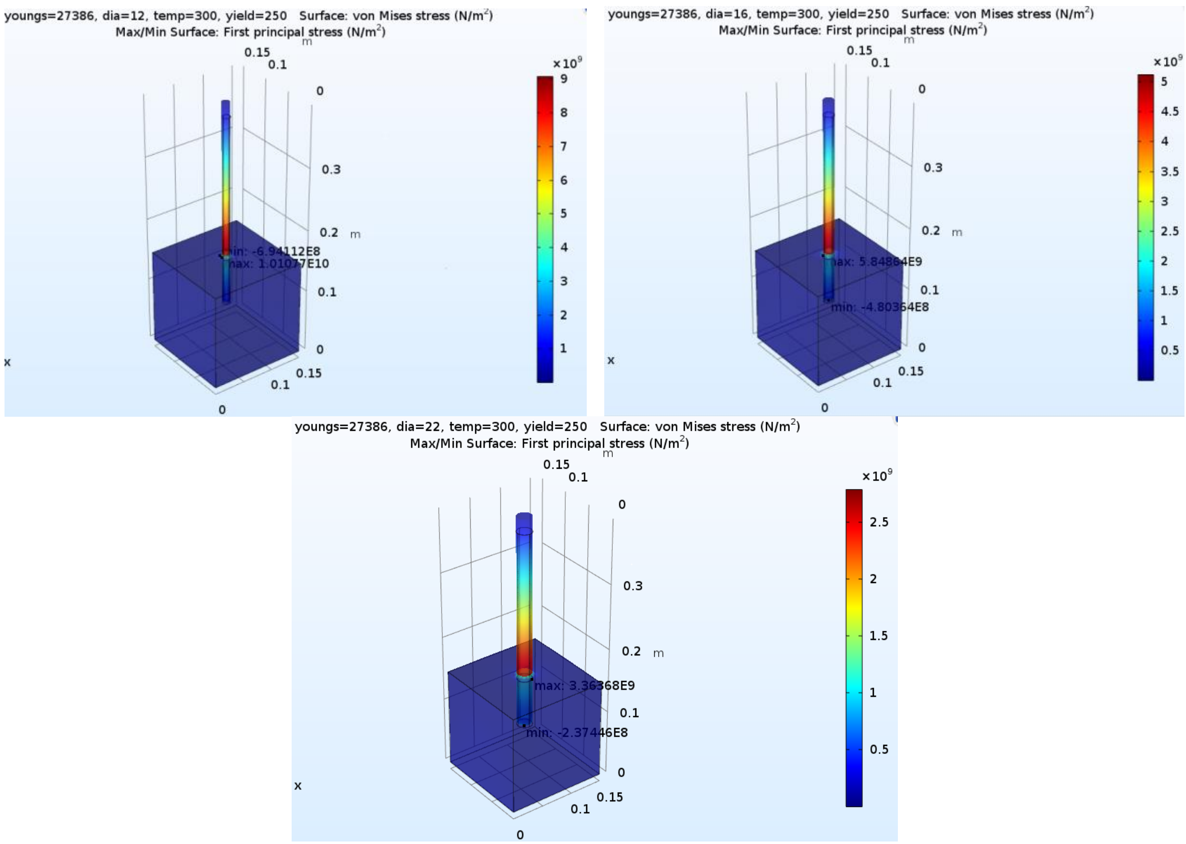


Figure 2: Stress distribution plots of the specimens by COMSOL for varying diameter of the steel

Effect of embedded length of steel and concrete strength

Increase in the depth of reinforced steel in concrete, increase the bond strength and influence the stress distribution on the surface of the steel when subjected to the pulling force on to the top of the steel. The variation of the stress distribution in the specimen is 32 % for change in the depth of embedded steel from 50 mm to 75 mm and 11 % for change from 75 mm to 150 mm. The overall percentage increase in the stress is 46 % for change in the depth of steel from 50 mm to 150 mm. Figure 3 shows distribution of stress in pull out specimens. In figure 3, the red patches in the model, indicates the maximum stress distribution near the top surface specimen and there is subsequent reduction of the stress occurs when moves towards the tips of the steel rod. The influence of the concrete strength in bond strength of the pull out specimens was analysed using equations proposed by researches listed in the Table 1. Figure 4 shows bar chart between the bond strength – embedded length of the steel reinforcement for different diameter of the steel obtained using COMSOL.

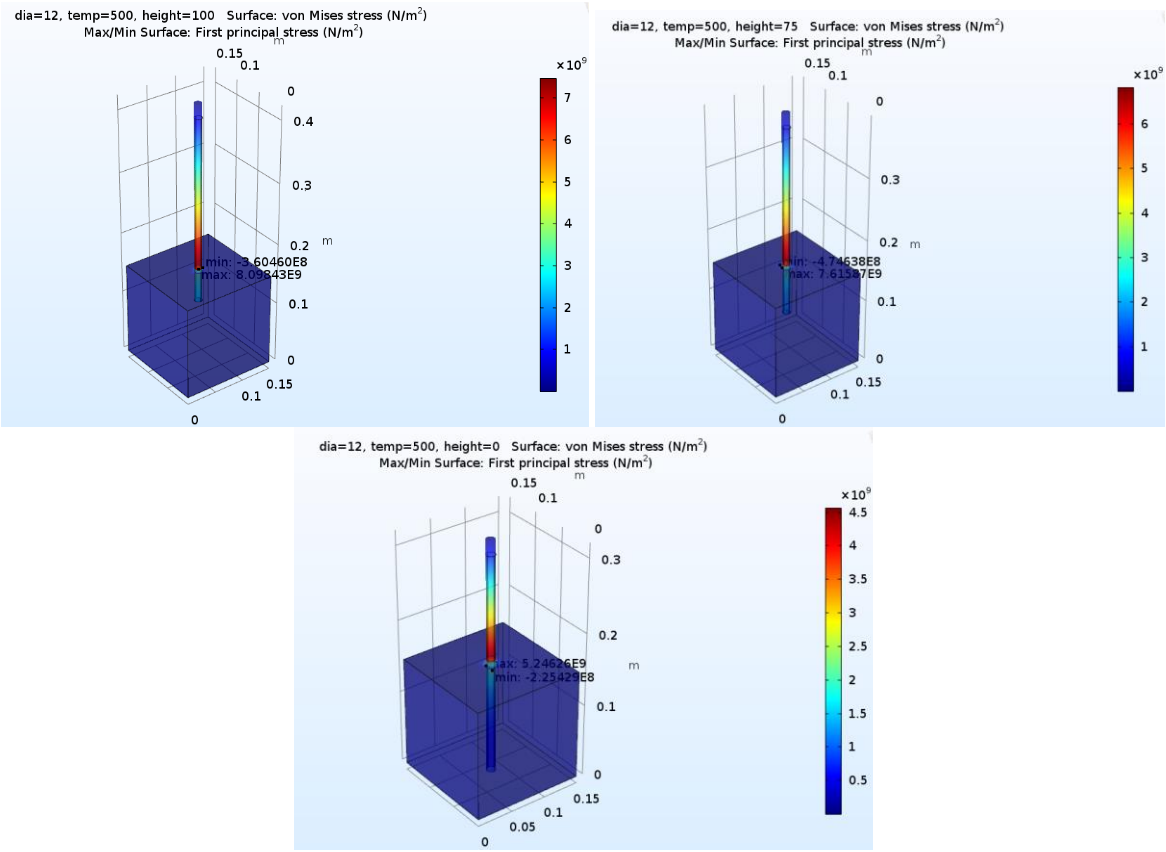


Figure 3: Stress distribution plots of the specimens by COMSOL for varying embedded length

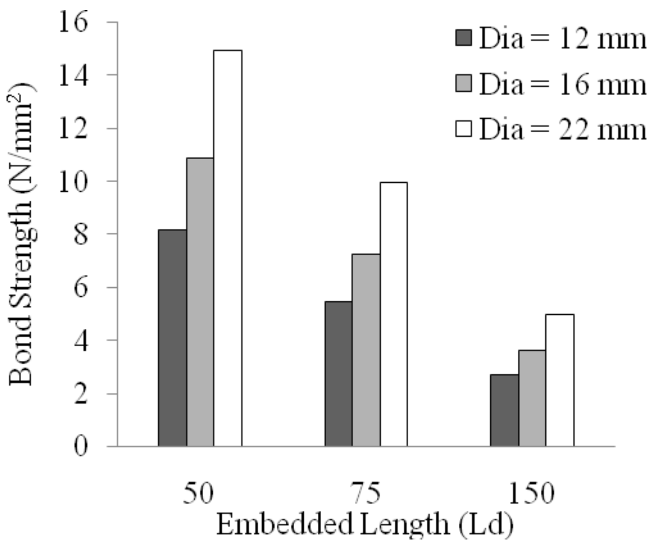


Figure 4: Comparison between embedded length and bond strength for different diameter of the steel (COMSOL)

The bond strength from the analytical study using COMSOL was formulated by using the formula (1) below

$$\tau = \frac{P}{\pi Ld} \quad (1)$$

Where P = Maximum load
L = Embedded length of the steel
d = diameter of the embedded steel reinforcement

Indian Standard IS 456-2000, recommends the following equation (2) to find the bond strength in N/mm^2

$$\tau = \frac{\phi\, \sigma s}{4\,x\,1.6\,Ld} \quad ; \qquad \sigma_s = 0.87 f_y \tag{2}$$

where ϕ is the diameter of the embedded steel in mm, f_y is the yield strength of mild steel in N/mm^2, Ld is the embedded length of reinforcing steel in mm.

Many researchers have formulated equations to find the bond strength between the reinforcing mild steel bars and the concrete. They are given below.

Orangun et al. (3) predicted the equation to find the bond strength between the steel and concrete in pull out specimen.

$$u = 0.083045\sqrt{f_c'}\left[1.2 + 3\frac{c}{d_b} + 50\frac{d_b}{L_d}\right] \tag{3}$$

where *c* = cover of the concrete in mm and *f'c* is the compressive strength of concrete in MPa.

Darwin et al. (4) have given a modified expression to find the bond strength and all the terms are expressed in SI units.

$$u = 0.083045\sqrt{f_c'}\left[\left(1.06 + 2.12\frac{c}{d_b}\right)\left(0.92 + 0.08\frac{C_{max}^*}{C_{min}}\right) + 75\frac{d_b}{L_d}\right] \tag{4}$$

where : $C = \min(C_x, C_y, C_s/2)$ and $C_{max}^* = \max\left[\min(C_x, \frac{C_s}{2}), C_y\right]$

Cx is the side cover in mm, *Cy* is the bottom cover in mm and *Cs* is the spacing between the steel rods in mm.

Australian Standard 3600 (5) recommends the following expression to find the bond strength.

$$u = 0.265\sqrt{f_c'}\left(\frac{c}{d_b} + 0.5\right) \tag{5}$$

Esfahani and Rangan (6) proposed the following expression for specimens made from high strength concrete having compressive strength ≤ 50 MPa.

$$u = 8.6\frac{C/d_b + 0.5}{C/d_b + 5.5} f_{ct} \tag{6}$$

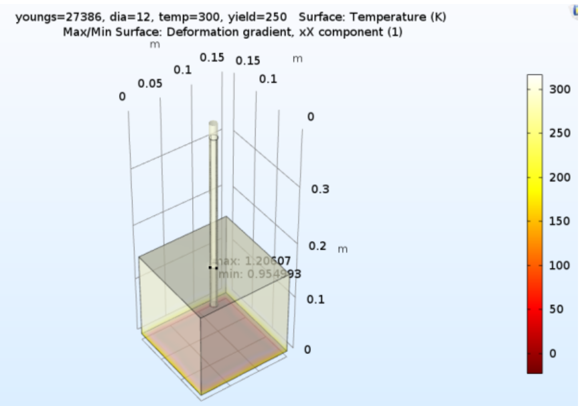
where C is the minimum cover between steel and concrete in mm and fct is the tensile strength of concrete which can be 0.55 times $\sqrt{fc'}$ in MPa. The bond strength calculated using COMSOL and also using expression proposed by many researchers for different specimens was given in Table 1.

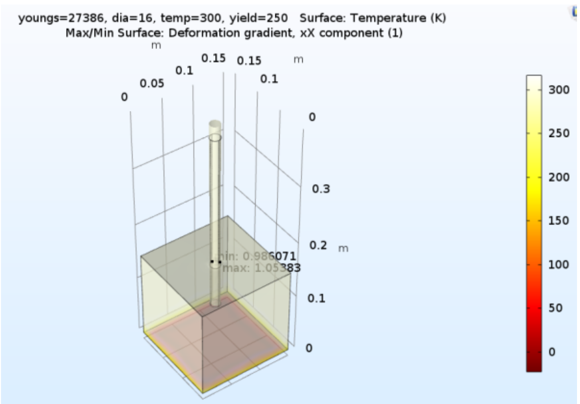
Table 1: Comparison of bond strength for different specimens using COMSOL with expression proposed by many researchers

Specimen No	Φ mm	f_y N/mm^2	l_d mm	COMSOL (1)	IS 456 (2)	Orangun et al. (3)	AS 3600 (4)	Esfahani & Rangan (5)	Darwin et al. (6)
Φ 12 Ld 50	12	250	50	10.61	8.16	13.85	9.07	14.39	14.43
Φ 16 Ld 50	16	250	50	7.96	10.88	13.53	6.80	12.54	15.61
Φ 22 Ld 50	22	250	50	5.79	14.95	14.52	4.95	10.50	18.45
Φ 12 Ld 75	12	250	75	7.07	5.44	13.89	10.48	16.62	16.46
Φ 16 Ld 75	16	250	75	5.31	7.25	12.83	7.86	14.48	17.86
Φ 22 Ld 75	22	250	75	3.86	9.97	12.92	5.71	12.13	21.18
Φ 12 Ld 150	12	250	150	4.42	2.72	13.18	11.71	18.58	18.40
Φ 16 Ld 150	16	250	150	3.32	3.63	11.21	8.78	16.18	19.99
Φ 22 Ld 150	22	250	150	2.41	4.98	10.14	6.39	13.56	23.68

Effect of Temperature

The pull out specimens were also analysed using COMSOL for bottom surface temperature of 300 K for different diameter of steel bars and embedded length of steel reinforcement in concrete and also for different strength of the concrete. The maximum and minimum stress for all the specimens was found using COMSOL and tabulated in Table 2. The Figure 5 shows the distribution of the stress in the pull out specimens for temperature of 300 K. Table 3 gives the maximum and minimum deformation of the specimens for varying temperature. From table 2 it is observed that for the constant surface temperature of 300 K, the stresses developed in the specimen decreases with increase in the diameter and increase in the concrete strength. The table 3 gives that increase in surface temperature from 300 K to 500 K, decreases the gradient deformation where as for change in temperature from 500 K to 1000 K increases the gradient deformation slightly.





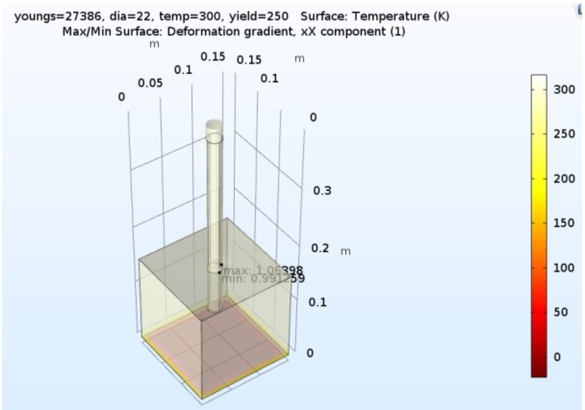


Figure 5: Stress distribution plots of the specimens by COMSOL for temperature of 300K

Table 2: Maximum and minimum stress for different specimens

Sl.No	Diameter of steel mm	Yield strength of Steel (N/mm²)	Concrete Grade	Young's modulus (N/mm²)	Temperature (K)	Maximum stress (kN/mm²)	Minimum Stress (kN/mm²)
1	12					10.110	0.694
2	16	250	M30	27386	300	5.849	0.480
3	22					3.364	0.237
4	12					10.110	0.694
5	16	250	M40	31622	300	5.849	0.480
6	22					3.364	0.237
7	12					10.110	0.694
8	16	250	M50	35355	300	5.849	0.480
9	22					3.364	0.237

Table 3: Maximum and minimum gradient deformation for varying diameter and temperature

Sl.No	Diameter of steel Mm	Yield strength of Steel (N/mm²)	Young's modulus (N/mm²)	Temperature (K)	Maximum Deformation (mm)	Minimum Deformation (mm)
1	12			300	1.206	0.955
2	16	250	27386	500	1.054	0.986
3	22			1000	1.064	0.991

CONCLUSION

The finite element analysis using COMSOL software was carried out to find the bond behaviour between embedded steel in the concrete. In the pull out specimens the parameters changed are diameter of the reinforcing bar, strength of concrete, embedded length of the bars and surface temperature of the specimens. The following conclusions were arrived.

1. The bond strength obtained from the model using COMSOL was 30 % difference in the strength when compared to the strength obtained using codal provision by IS 456.
2. The bond strengths was calculated by the equations proposed by the many researches shows the good agreement with the analytical results.
3. At room temperature of 300K, there were decrease in the bond strength between the embedded steel and concrete irrespective of increase in diameter of reinforcing steel bar and strength of concrete cube.

4. The increase in the embedded length and increase in the concrete strength decreases the bond strength by 33 % for the constant diameter of the reinforcing steel bar in concrete.
5. The deformation of the pull out specimens were got decreased for change in surface temperature of the bottom side of the cube from 300 K to 500 K and then increased for change in temperature from 500 K to 1000 K.

List of Symbols

A_b	=	Nominal cross-section area of reinforcing steel in mm^2
A_{st}	=	Cross section area of tensile reinforcement in mm^2
c	=	Concrete cover in mm
C^*_{max}	=	Highest value of C_x and $C_s/2$ and C_y
C_{min}	=	Smallest value of C_x, C_y, $C_s/2$
Cs	=	Spacing between the reinforcing bars in mm
Cx	=	Side cover in mm
Cy	=	Bottom cover in mm
d_b	=	Nominal diameter of the reinforcing bar in mm
dx	=	Shortest length of beam in mm
f'_c	=	Compressive strength of concrete in MPa
f_{ct}	=	Tensile strength of concrete in MPa
f_s	=	Maximum stress in reinforcing bar in MPa
f_y	=	Characteristic yield strength of steel reinforcing bar in MPa
L_d	=	Embedded length of reinforcing bar in mm
P_{max}	=	Maximum pullout load in kN
u	=	Bond strength of the specimen in MPa

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