ANALYSIS OF INTERFACIAL STRESSES BETWEEN COMPOSITE REBAR AND CONCRETE

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ABSTRACT

The objective of this study is to investigate and compare the interfacial stresses between glass-fiber reinforced polymer (GFRP) composite rebar and concrete under axial loading. Rebars of three different cross-sections are considered: circular one and circular with two and four longitudinal ribs. The design analyses of the rebar configurations embedded in concrete are investigated by the 3D finite element method (FEM) using ANSYS software. FEM results convergence was examined with different FE mesh sizes comparing the calculated stresses. The influence of rib geometry on the operating stresses was also studied. The results of the interfacial stresses calculated are applied as a basis for estimation of the effectiveness of composite rebar configurations in concrete structures, which can provide good bond characteristics.

Key words: composite rebars, design analysis, concrete structure, parametric study

INTRODUCTION

Fibre reinforced polymer (FRP) bars have become commercially available as reinforcement for concrete over the last decades. Durability, lightweight, long fatigue life and good corrosion resistance in aggressive environments are the main reasons of implementation into the civil engineering structures (Barboni et al., 1997, Emmons et al., 1998, Midwater et al., 1997, Nanni et al., 1995, Bakis et al., 1998).

Composite rebars made of glass, carbon and aramid fiber reinforced composites can be readily formed into complex shapes through the pultrusion manufacturing process. (Wallenberger et al., 2001, Walsh, 2001).

The most common manufacturing process is the pultrusion process, when the longitudinal fibers are drawn through a resin bath and then passed through a die, which gives the rebar of a final shape.

Recent studies have shown that, generally, the bond between the concrete and smooth FRP rods is affected by the non-isotropic mechanical properties of the FRP. The mechanical properties in the longitudinal direction are controlled by the fibres, but the stiffness and strength in the transversal direction depend on the resin matrix, low elastic modulus which can reduce the bond strength (Al-Zahrani et al., 1995). Moreover, the relative smoothness of FRP rods in the longitudinal direction compared to steel reinforcing bars can also reduce friction and thus the bond strength with concrete.

Additional techniques are required to improve the bond between the rebar and the surrounding concrete. Several techniques can be used, including surface deformations, sand coating, over-moulding a new surface on the bar or a combination of the techniques. Many researchers have brought up various formulae to estimate the bond strength of deformed composite reinforcement and studied experimentally and numerically the use of composite rebars as reinforcement in concrete structures.

Tighiouart et al. (1998) presented experimental investigations of concrete beams reinforced with two types of FRP rebars. The results of the tests indicated that the applied tensile load approached the tensile strength of rebars as the embedment length increased and the GFRP rebars showed lower bond strength values compared to steel rebars. The average maximum bond strength of the FRP rebars depends on the diameter and the embedment length. The GFRP rebars showed lower bond strength values compared to steel rebars. Nanni et al. (1994) presented experimental and analytical results for beams reinforced with hybrid rebars for the evaluation of the flexural behavior of the composite system. The tensile and interface bond strengths of composite rebars are the most important characteristics for establishing design procedures for reinforced composite concrete structures. Mirmiran and Shahawy (1996) considered that an effective use of fiber-reinforced plastic (FRP) rebar shapes in infrastructure is in the form of composite construction with reinforced concrete.

The finite element research of composite rebars with different shape has been proposed by (Kadioglu, 2005). Specifically four different composite rebar configurations under axial, bending and torsional loadings are investigated using the 3D finite element analysis. The composite rebar configurations investigated include square rebar, circular rebar with ribs, and ribs oriented at an offset angle along the length of the rebar. The results of interface stresses obtained are presented and compared among various rebar configurations under axial, bending and torsional loadings. The idea of using ribs is to improve the bond characteristics with the surrounding concrete. The results presented in this research illustrate that various design features added to the circular composite rebar may provide good bonding characteristics and can be used in reinforced concrete structures.

The objective of this study is to investigate and compare the interfacial stresses between glass-fiber reinforced polymers (GFRP) composite rebar and concrete under axial loading using finite element software. The influence of rib geometry on the operating stresses is presented to illustrate the effectiveness of composite rebar configurations in beam type reinforced concrete structures. The bond stress of a usual smooth composite rod was used as reference.

COMPOSITE REBAR

Materials and configuration

Three different types of concrete composite rebar configurations for improving the bond properties under axial loading are considered in this research. The first rebar R1 (Fig. 1*a*) has a standard circular cross-section that is commonly used in construction industry (Fig. 1). The second R2 and third R3 rebars have circular cross-sections with two and four longitudinal ribs respectively (Fig. 1*b*, *c*).

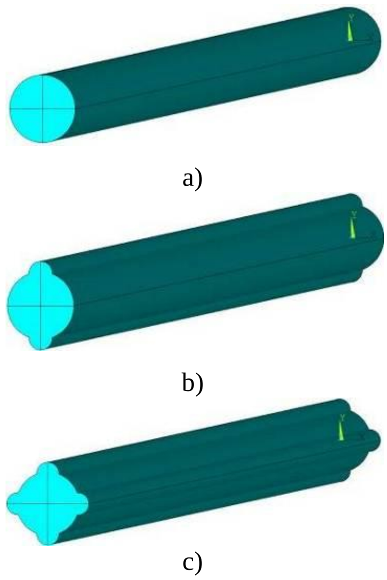


Figure 1. Shape of rebars (R1), (R2) and (R3)

Other possible configurations of this rebar type are not considered in this study. All rebars are made of fiber-reinforced polymer composite, which can be easily manufactured through the pultrusion process. Composite rebar embedded in a cylindrical concrete block: D = 39 mm (diameter) and L = 20 mm (length). The height of rib (h) is 2 mm, width of rib (w) is 4.5 mm, diameter of rod (d) is 13 mm and length of composite rebar (l) is 250 mm (Fig. 2).

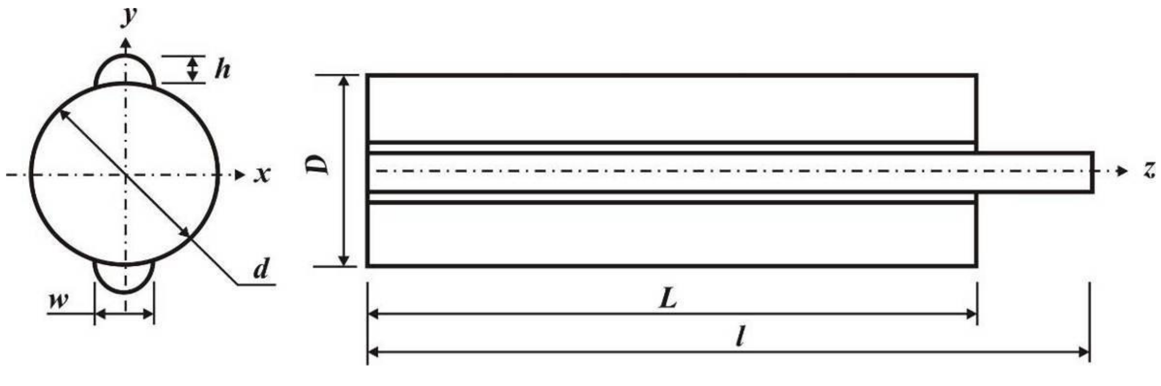


Figure 2. Cross-sectional geometry of a composite rebar R2

The following properties are used in the finite element analysis for the concrete (E = 30 GPa and v = 0.15) and composite rebars UD GFRP/epoxy (E_1 = 54 GPa; E_2 = E_3 = 18 GPa; G_{12} = G_{13} = 4.9 GPa, v_{12} = v_{13} = 0.25).

Uniaxial loading was carried by axial displacement of 2 mm applied to one side of the composite rod with rebars.

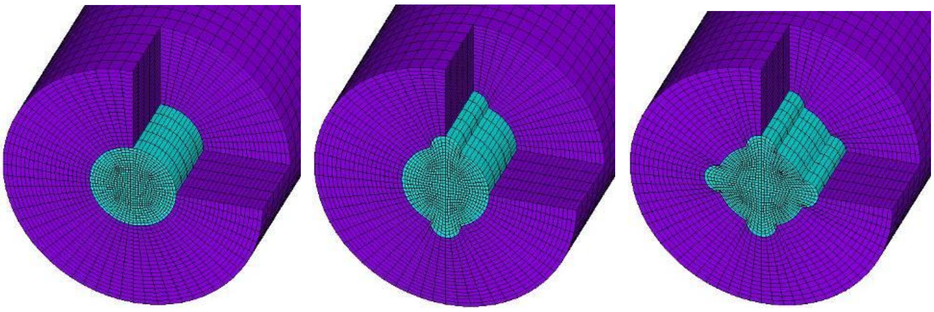
Finite element models

The 3D finite element models of the composite rebars and the surrounding concrete were simulated by software ANSYS. The composite rebar and concrete are modelled using 3D brick elements SOLID185. The SOLID185 element type is defined by eight nodes and has three degrees of freedom (translations in *x*, *y*, *z* directions) at each node. The concrete rebar having circular and circular with ribs configurations enclosed in a concrete block are considered. Due to the geometrical symmetry of the configurations considered, one quarter of their volume was modelled.

At the beginning, it is necessary to conduct the convergence tests for the finite element model developed and validate the correctness of FEM discretization for the next calculation work. Convergence of the FEM results was examined for several models with different mesh sizes and by comparing the resulting stresses. Based of these results, the appropriate mesh with brick finite elements was chosen as primary for FEM model.

Fragments of FEM models are shown in Fig. 3 for rebars with different cross-sections.

All calculations were made with the finite element method by creation of a friction interface between the composite rod and concrete. 3D contact FEM problems for the research system were considered and the compressive strength is analyzed.



a) b) c)

Figure 3. Finite element models for composite rebars R1 (a), R2 (b) and R3 (c)

RESULTS AND DISCUSION

Interfacial stresses distributions

The distribution of interfacial shear stresses τ_{yz} at the interface of the rebars R1, R2 and R3 under axial loading is shown in Fig. 4.

It is seen that the rebar with 2 ribs is subject to shear stress of about 25 % higher than the rebar with 4 ribs ($|\tau_{yz}^{\max}|$ = 51.3 and 38.3 MПa, respectively). Moreover, location of maximum shear stress depends also on the rebar configuration (Fig. 5).

Rib height effect

An important geometrical parameter of the rebars is the height of the ribs. The results presented in Fig. 6 illustrate the influence of the rib height on the maximum interfacial shear stresses for rebars with 2 ribs and 4 ribs under axial loading. The width of the ribs was 4.5 mm in all rebars studied.

It is seen that the maximum interfacial shear stresses for the rebar with 2 ribs is much higher than with 4 ribs. Depending on the rib height, this difference changes from 25% (*h* = 2 mm) to 45% (*h* = 4 mm).

Rib height and width effect

The following step of FEM calculations was concerned with estimation of interfacial shear stresses in the case of simultaneous variation of the rib height and width. The maximum interfacial shear stresses calculated for rebars with 2 and 4 ribs under axial loading are shown in Figure 9.

The data of Figures 10 and 11 show the distribution of interfacial shear stresses along the length of the rebars with 2 and 4 ribs depending on the rib height and width.

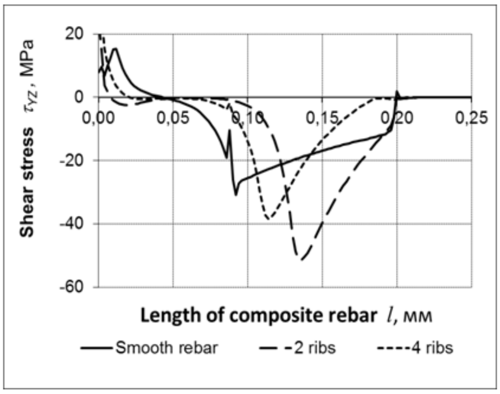


Figure 4. Distribution of interfacial shear stresses at the interface of the rebars R1, R2, R3

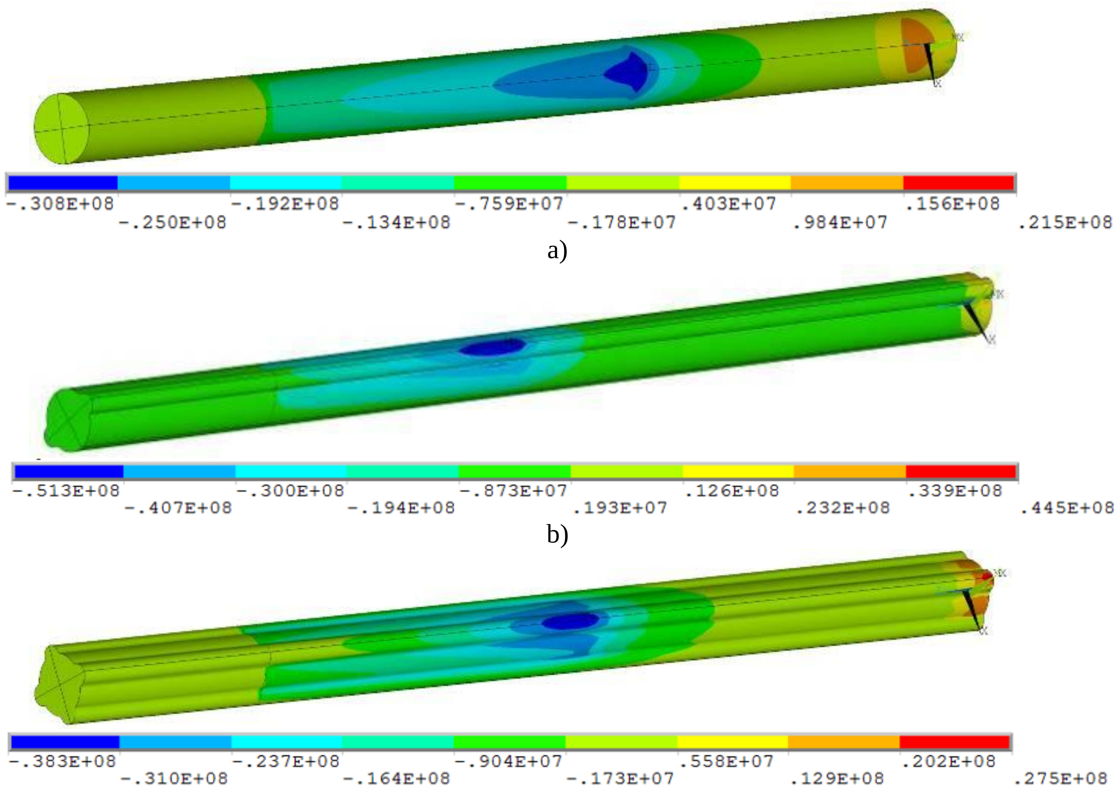


Figure 5. Distribution of shear stresses in rebars R1 (a), R2 (b) and R3 (c)

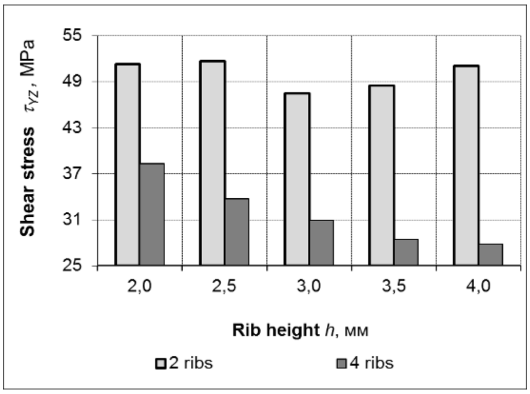


Figure 6. Maximum interface shear stresses for rebars R2 and R3 via rib height

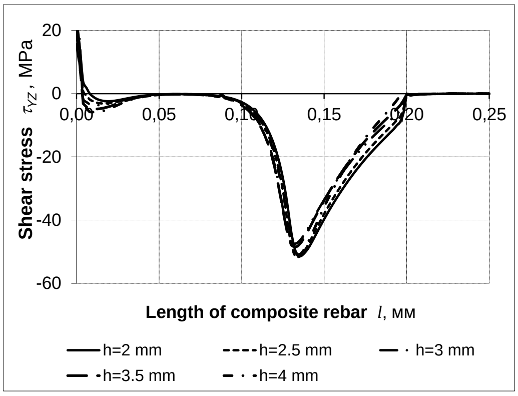


Figure 7. Shear stress distributions in rebar R2

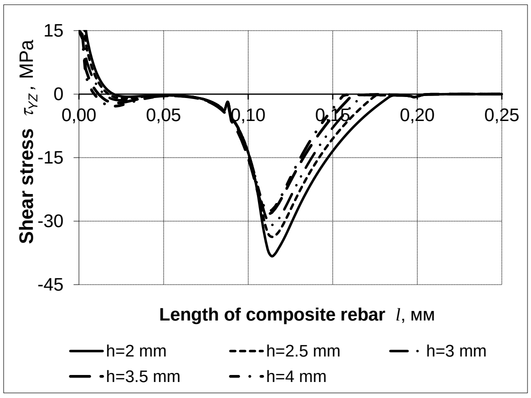


Figure 8. Shear stress distributions in rebar R3

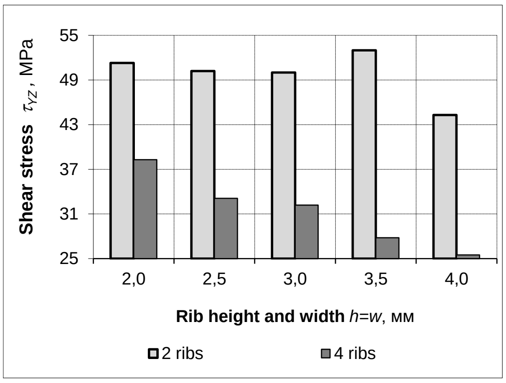


Figure 9. Maximum interface shear stresses for rebars R2 and R3 via rib height and width

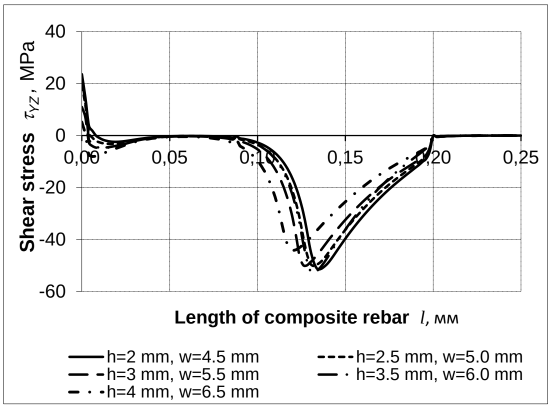


Figure 10. Shear stress distributions in rebar R2

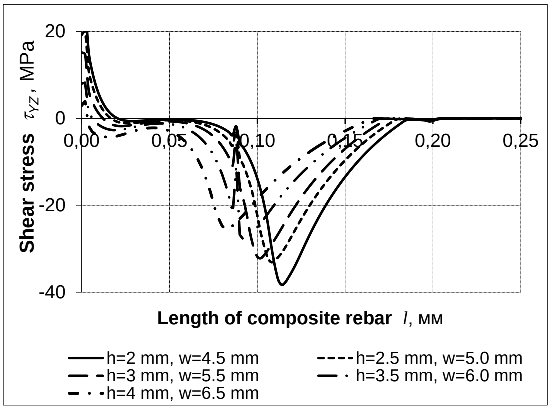


Figure 11. Shear stress distributions in rebar R3

CONCLUSION

The numerical stress analyses for the composite rebars embedded in concrete are investigated by the 3D finite element method (FEM) using ANSYS software. The rebars of circular cross-section with two and four longitudinal ribs, as well without ribs were studied. Based on the results of the preliminary parametric analysis of interfacial shear stresses under uniaxial tension of the composite rebars, the following conclusions can be made.

- Number of the longitudinal ribs influences significantly on the mechanical bond between composite rebars and concrete.
- In the case of rebars with four longitudinal ribs, maximum shear stresses $\tau_{yz}^{\max}$ are 25% less then that for rebars with two ribs.
- It was shown that height and width of the ribs were also strongly effect of the magnitude of interfacial stresses $\tau_{yz}^{\max}$.

Thus, solution of the optimization problem with searching the optimal set of the parameters of composite rebars enhancing their mechanical bond with concrete will be the further step of the investigation.

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