FE ANALYSIS OF BOND FOR SMOOTH FRP RODS EMBEDDED IN CONCRETE

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Summary The main objective of this paper is to propose a reliable method for numerical analysis of the bond interaction between FRP composites and concrete. The outline of research is based on a numerical simulation of an experiment, conducted in literature. Friction and chemical adhesion are the presumed factors supplying bond resistance. Contact parameters are evaluated and calibrated. Numerical graphs are compared with tentative results as a validation. Curves indicating changes in tangential and normal statue of the interface are shown.

Theory of bond of smooth rods with concrete

Application of the FRP reinforcement in modern concrete structures is increasing, in comparison with common techniques to inhibit or eliminate corrosion. Currently three types of fiber reinforcement are commonly used in polymer matrix composites; carbon, glass, and synthetic polymer fibers such as Kevlar [1]. It can be stated that whatever test procedure and mechanical properties are used, poor bond strength for smooth rebar with concrete will be obtained [2]. At early stages of loading, the bond shear force is dominated by chemical adhesion, which demolishes quickly and friction plays the main role in supplying bond resistance afterwards. The interface condition is affected by physical, chemical, and thermomechanical compatibility of the composite components with the outside environment [3].

FE modelling and the contact parameters

Figure 1 shows the configuration of the model simulated in this study. GFRP composite rod, which comprises E-Glass fibers and Vinylester matrix, was applied in the test. Appropriate thermal performance as well as excellent mechanical properties and toughness are the major causes for application of vinylester resins [4]. Modelling is performed in bar-scale mode. In this kind of simulation, the interface of rod with concrete is idealized by a cylindrical shape. Note that the proposed model is based on an FE simulation of a test carried out by Al-Zahrani et al. [5]. Non-linear spring and contact elements are employed to model the chemical adhesion and frictional behaviour between the concrete and rod respectively.

Contact parameters are: normal stiffness K_n, tangential stiffness K_s, coefficient of friction μ and initial interference δ. A consecutive procedure is used to obtain the true values of K_s and K_n parameters [6]. The initial interference which has been measured in test is 3.5~3.6 μm [5]. It is worth noting that the initial interference is normally a simulation of contact pressure along the interface, produced by a change in thermal situation due to cement hydratation. According to test, a 40°C decrease in the temperature of system results in an approximately 0.7 MPa reduction in average bond strength. The temperature of the analytical model is reduced in a similar way. Several consecutive analyses are carried out by increasing the coefficient of friction; μ, of the interface gradually, till a similar decrease of bond strength is gained numerically. It must be noted that the procedure of proposing the contact parameters involves three stages: Evaluation, Calibration and Validation. Finally, the values K_s=5.0E7; K_n=2.0E9; μ=0.21; δ=3.5 μm are proposed as evaluations of contact parameters. Authors calibrated the parameters by a comparison between numerical and experimental load-slip graphs [6] and concluded that the best coincidence is observed for μ=0.18. Note that a little change for any of the parameters at calibration stage is permitted.

Numerical Results

Al-Zahrani [5] carried out his experiment using three gages on the external surface of smooth rod at equal distances. To validate the proposed contact parameters, theoretical and tentative curves of bond stress-strain are compared in Figure 2. Figure 3 illustrates the mechanical behaviour of the interface. The linear branch (I) indicates the opening behaviour, however the uniform branch (II) implies the slipping statue. When more pull-out load is exerted, the mechanical interference will be opened. This will result in reduction of F_n, considering the fact that F_n is proportional to the value

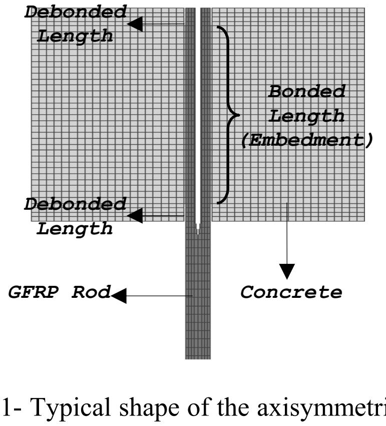

Figure 1- Typical shape of the axisymmetric FE model.

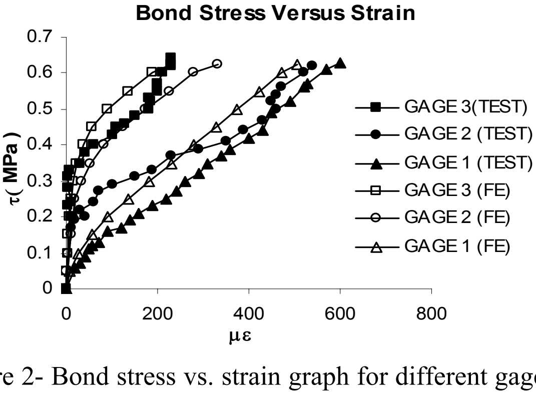

Figure 2- Bond stress vs. strain graph for different gages along the embedment.

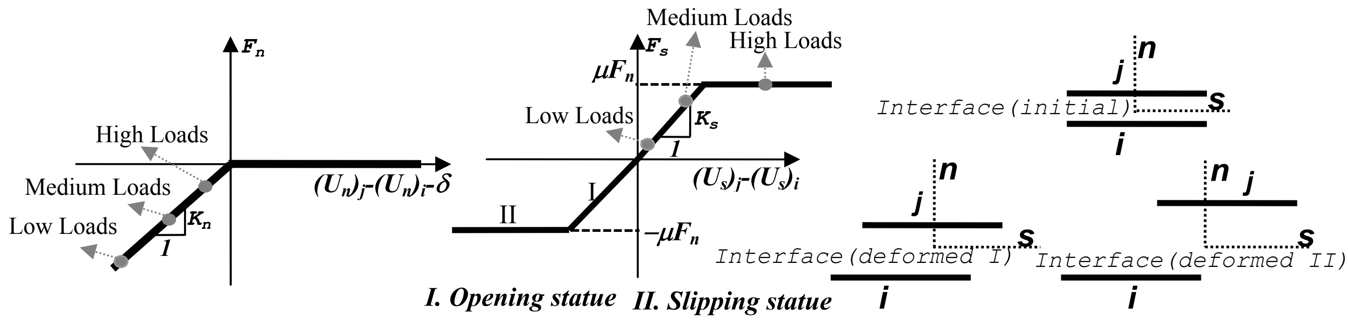

Figure 3- Normal and tangential mechanical behaviour along the boundary.

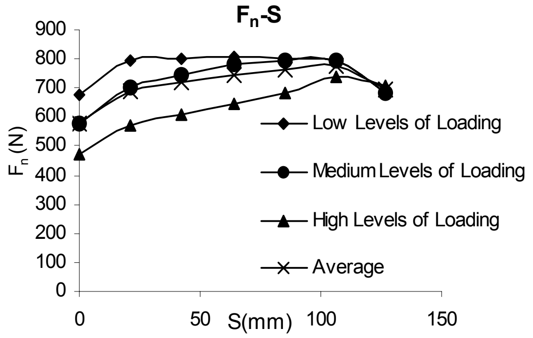

Figure 4- Variation of F_n along the embedment.

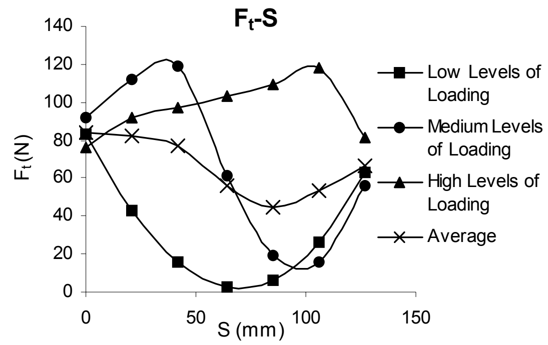

Figure 5- Variation of F_t along the embedment.

of interference while staying on part I of the graph. Decrease of F_n causes a subsequent reduction of the maximum bearable tangential force, which equals $\mu|F_n|$. Overall, it can be concluded that the contact elements throughout the boundary approach the slipping statue with an incremental rate by progress in loading. The maximum bond strength is obtained when all the contact elements along the boundary have either fallen into the slipping statue or the relevant mechanical interference has completely opened. Figure 4 shows the variation of interaction normal force along the contact embedment. At low and medium levels of loading, the minimum F_n takes place near the ends of the rod, which is mainly due to debonded lengths at both ends that result in stress concentration and decrease of resistance against radial dilation. At high levels of loading, the maximum value of F_n occurs nearly at the free end. This can be justified by the Poisson's rule, which states that the contraction of the rod in transverse direction decreases by reduction in the tensile force in longitudinal direction, while moving from the loaded-end part of the rod toward the free-end. Figure 5 illustrates the distribution of tangential force along the embedment. It is clear that the shear distribution is parabolic for low levels of loading. For high levels of loading, the distribution of shear force along the boundary is more uniform at and the maximum tangential shear can be measured at regions near the free-end of rod.

CONCLUSIONS

Contact and non-linear spring elements can be employed to simulate the frictional and adhesional function of the boundary of FRP and concrete respectively. Appropriate contact parameters were evaluated and calibrated, which are: K_n=2.0E9; K_s=5.0E7; μ=0.18; δ=3.5 μm. Cement hydratation of in-cast concrete results in a mechanical interference along the contact boundary, which opens gradually by progress in loading. Reduction in the temperature of reinforced system causes a consequent decrease of bond strength. Existence of debonded lengths culminates in low values of normal interaction between two materials at the ends of the rod, for average levels of loading. It was observed that the variation of bond tangential shear throughout the boundary becomes more complicated gradually by intensification of pull-out load. Finally, it has been concluded by comparison of numerical and experimental curves that the proposed model can be effectively used for simulation of bond behaviour between smooth FRP rods and concrete.

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