LAMINATED GLASS FIBER REINFORCED PLASTIC (GFRP) BARS IN CONCRETE STRUCTURES

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SUMMARY

This paper is based on my Ph.D. studies, on Non-Metallic fibers in concrete structures. In terms of this investigation the authors made GFRP bars in the laboratory. Those GFRP bars are made by hand lay-up laminating using conventional rollers. The glass fibers are embedded in a matrix of epoxy resin. For design reasons to the concrete beams, experimental tests have been done with the developed GFRP bars. The GFRP elements applied in structural concrete (beams) are unidirectional laminates in the shape of rectangular bars and strands. Following the development of these bars based on glass fiber experimental tests with the developed GFRP bars have been done in order to investigate the tensile strength, elasticity modules and bond strength of the GFRP bars in concrete.

Key words: Laminated, GFRP, tensile strength, elasticity modules, bond strength

1. INTRODUCTION

The aim of this investigation was to apply the developed GFRP bars in lieu of conventional steel reinforcement in concrete structures. The elasticity modules of these GFRP bars would be higher than that of we get experimentally, while the production of those bars could be better in the sense that we could better prestress the glass fiber in a better way prior to its impregnition to the epoxy. However the exploited values for the tensile strength and modules of elasticity of the above-mentioned GFRP bars are comparable with similar investigations of different authors. While the axial tensile strength under short-term or long term force is one of the most important properties to structural design a special attention has to be given to get sufficient strength. It is one of the essences to exploit the highest level of structural utilization.

The experimental results of short time pull-out tests of the GFRP bars in concrete specimens and bending tests of concrete beams reinforced by GFRP bars are presented in detail on the paper. The theoretical predictions for the values of tensile strength and elastisity modules of the GFRP bars are also presented in the paper. The results of experimental investigations of the tensile strength elastisity modules and the bond tests of the developed GFRP bars were the base to the design of concrete beams reinforced with GFRP bars.

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2. THEORETICAL CALCULATIONS FOR THE TENSILE STRENGTH AND ELASTISITY MODULES OF GFRP BAR

For theoretical calculations, we suppose an ideal adhesion between the fibers and the matrix. Neglecting the volume of the cavities, which is impossible to eliminate during lamination from the composite, and supposing the composite as a composition of the matrix and the fibers it is possible to interpret the following relations:

$$V_f = v_f / v_c \ , \quad V_m = v_m / v_c \ , \quad V_c = v_c + v_c \tag{1.1}$$

$$\varepsilon_f = \varepsilon_m = \varepsilon_c \quad \leq \varepsilon_{laminate} \tag{1.2}$$

Where v_f, v_m, v_c are the volumes of the fibers, matrix and composite,
ε_f, ε_m, ε_c, are the deformations

The fiber or matrix volume content in unidirectional laminated members in a plain can be calculated as the:

$$V_f = S_f / S_c, \qquad V_m = S_m / S_c \tag{1.3}$$

Deriving eq. (1.3) according to ε - (1.2) we get:

$$E_C = E_f V_f + E_m V_m \tag{1.4}$$

Where $E_{c, f, m}$ are the elasticity modulus of the composite, fiber and matrix

An important relation to practice for stress and load relations:

$$\sigma_f / \sigma_m = E_f / E_m, \ \sigma_f / \sigma_c = E_f / E_c \tag{1.5}$$

$$F_f / F_m = (\sigma_f V_f / \sigma_m V_m) = (E_f / E_m)(V_f / V_m) \tag{1.6}$$

$$\frac{F_f}{F_c} = \frac{E_f \varepsilon_f V_f}{E_f \varepsilon_f V_f + E_m \varepsilon_m V_m} = \frac{E_f / E_m}{(E_f / E_m) + \left(\frac{V_m}{V_f}\right)} \tag{1.7}$$

From equation (1.4) it implies that the stress ratio in each component and in the composite as a hole shears according the modules of elasticity. Theoretically it is possible to produce a laminate of non-metallic fibers with a maximum content of 91% fibers-with round cross sectional areas, however exceeding 80% fiber content worsens the important characteristics of the laminated bars. Verification of the experimental values with the theoretical values is according to the mixing principle (1.4).

The tensile strength and the modules of elasticity gained in this experiment are comparable with similar investigations. Theoretical calculation for characteristics of FRP bars is based up on the percentage composition of the fibers. The results show a sufficient tensile strength (600MPa) to be applied in structural elements. The low modules of elasticity 40GPa of the GFRP bars contributed to greater deformations of the structural members. The different between theoretical values and experimental values were 6%.

3. INSTURMANTATION OF PULL-OUT TESTS

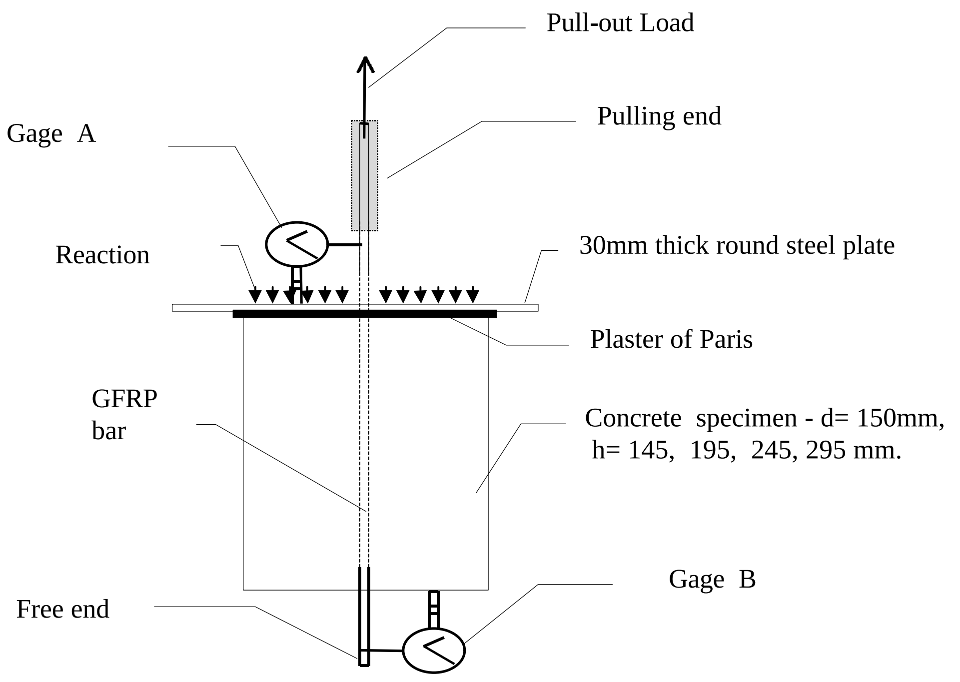

Fig. 1 Test set -up for bond test of GFRP bars embedded in concrete.

Pull-out test results of GFRP bars are given in Fig. 2 and 3. Rectangular GFRP bars which corresponds in area ϕ12 steel bars has been embedded in concrete specimens. Four embeddment lengths has been tested with GFRP bars, movement of GFRP bars has been monitored at the pull-out side end and at the free end of the bar Fig.1. The embeddment length of the bars were 12,16, 20 and 24 times of the bar diameter. The test configuration is given in Fig.1. Results showed that the bond sleep diagram of the GFRP bars are similar with the bond sleep diagrams of reinforcing steel. The pasted sand has been failed in some areas of the pulled GFRP bars, where the controlling factor in terms of bond strength appears to be the resin type rather than the fiber type. The bond strength of the laminated GFRP bars showed much more bond strength than the smooth bars. There were cases were the bond test has been interrupted do to concrete splitting.

Six concrete specimens of each batch has been tested in embeddment lengths of

145mm, 195mm, 245mm and three specimens with an embeddment length of 295mm. The 145mm embeddment length of GFRP shows an adequate bond strength, however the pull-out tests of two such specimens have been interrupted because the concrete specimens has been splitted. Pull-out tests with longer embeddment lengths ended, while the bar has been cutted due to tension, when the bars maximum tensile strength has been reached.

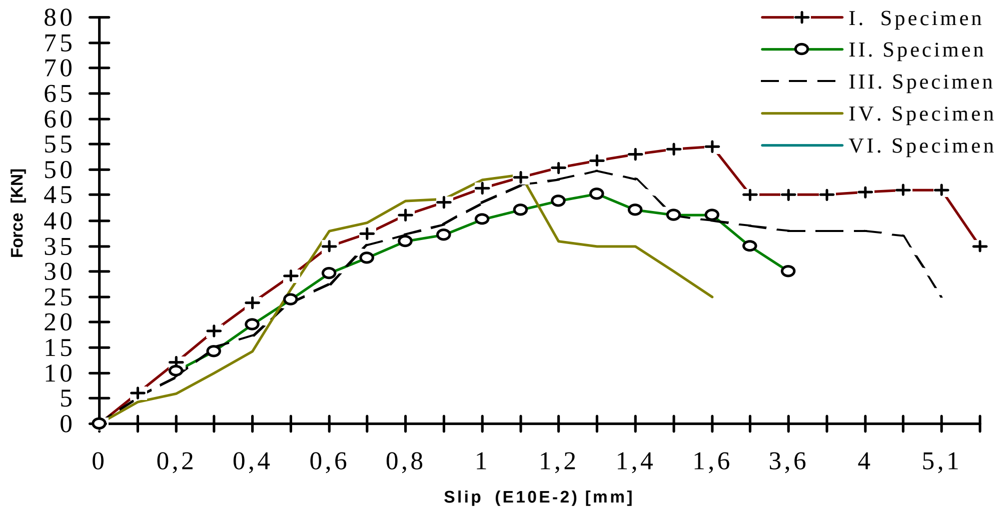

Fig. 2 Load sleep diagram of pull-out tests at the pulling end of laminated GFRP bars with an embedment length of 145mm.

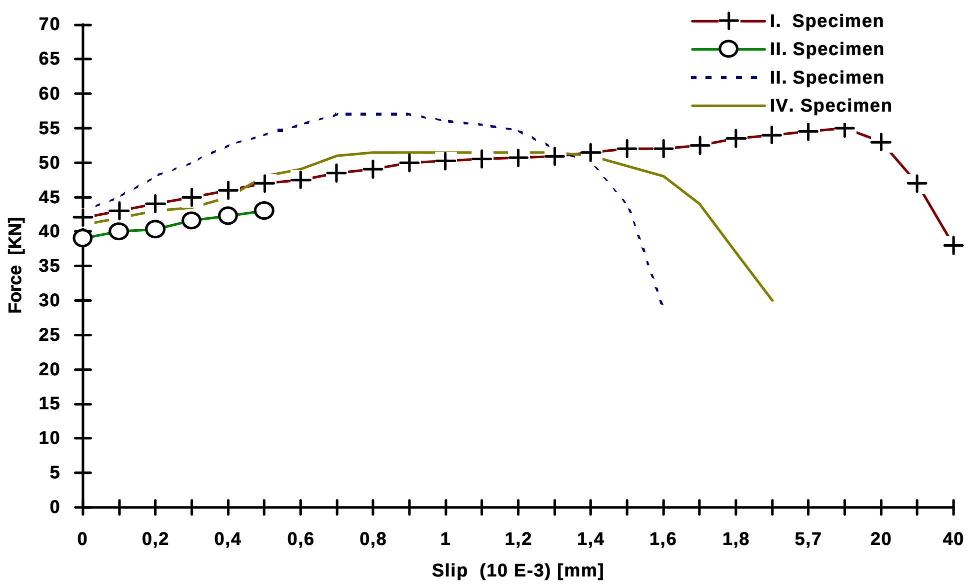

Fig. 3 Load sleep diagram of pull-out test of laminated GFRP bars at bottom end, with an embedment length of 145mm.

4. INSTURMANTATION OF BENDING TESTS OF CONCRETE BEAMS

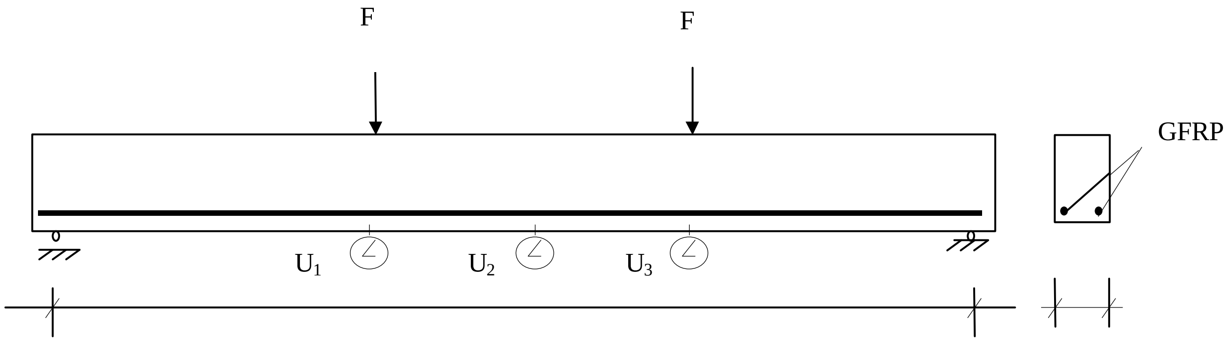

Fig. 4 Test set-up of the GFRP reinforced beam

Figure 4. shows the test set-up and the locations of the measuring parameters , where $U_{1,}$ $U_{2,}$ U_3 are vertical displacements every meter along the 3m long beam, F is the applied load in KN.

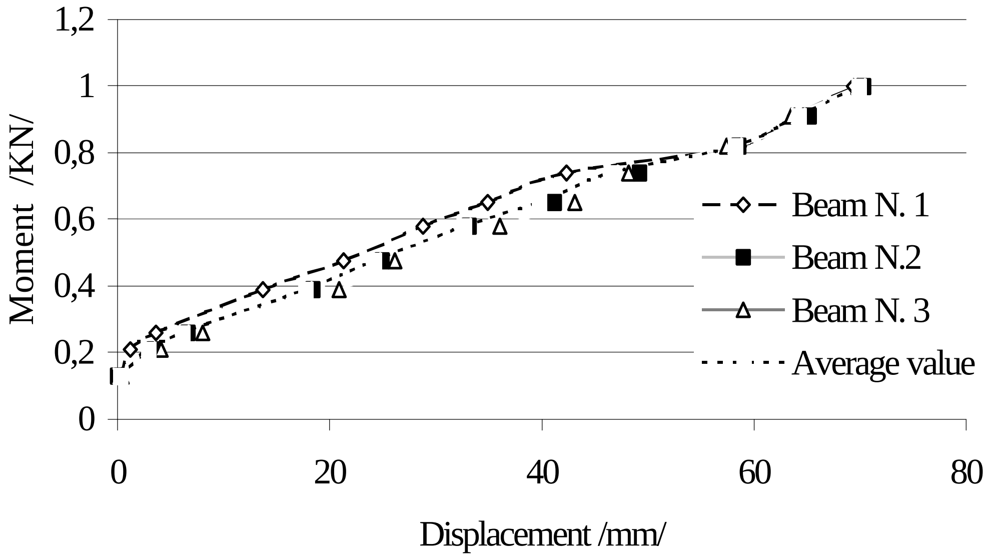

Fig. 5 GFRP reinforced concrete beams - Moment vs Displacement

Figure 5 shows mid span load / deformation diagram of the 3m long concrete beam reinforced with GFRP bar. In order to predict the ultimate capacities, we used simple formulas for computing moment and shear strengths. To compute ultimate moment capacity, it was assumed that failure occurs after the tensile GFRP yields, and when the reinforcement reaches its tensile capacity. these assumptions are in line with the absorbed behavior of the beams.

For comparison reasons concrete beams reinforced with conventional steel bars have been also experimented. Mid span load displacement of the steel reinforced concrete beams in compare with those GFRP reinforced beams were smaller.

5. CONCLUSIONS

Experiments show that the bond strength of the GFRP bars is sufficient to be applied in concrete structures. The sand pasted rough surface of the FRP bar assures a bond continuity and higher bond strength.

The experimental tests of concrete beams reinforced with GFRP bars show that their stiffness is affected by the low modules of elasticity of the GFRP. The FRP bars have more advantages comparing with steel, while they resist corrosion, alkaline and acid. They are also suitable in applications requiring less magnetic actions. The fact that they have lower modules of elasticity than steel could be detrimental for reinforced applications where deflections instead of strength should control the design, but would be more advantageous for prestressed concrete where will be lower tensile losses associated with shrinkage and creep of concrete.

6. REFERENCES

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