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EVALUATION OF THE STRUCTURAL RESPONSE OF DIFFERENT JOINT CONFIGURATIONS FOR PULTRUDED GLASS FIBRE REINFORCED POLYESTER BEAMS. EXPERIMENTAL SETUP

BY

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Abstract. This paper presents an experimental set up for the evaluation of structural response of glass fibre reinforced polyesters (GFRP) beams with different joint configurations. Five series of I-120×6 mm GFRP beams subjected to bending will be investigated to study the bending capacity of the bolted connections. The first series includes standard control specimens while the second and the third series specimens were joined mechanically with GFRP and steel plates using steel bolts. Series four and five contain specimens with mechanical-adhesively bonded joints and specimens with consolidated holes using bonded aluminium inserts. The test setup and instrumentation of specimens enable determining the failure loads observing the behaviour and failure modes of pultruded I-beams manufactured from glass fibre reinforced polyesters subjected to flexure.

Key words: composites; GFRP beams; bolted connections; hybrid joints.

1. Introduction

The necessity of using pultruded composite profiles in civil engineering structures due to its exceptional mechanical qualities and high resistance to

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corrosion attracted the attention of engineers and researchers soon after the development of pultrusion as a fabrication procedure for GFRP composite structural shapes. A decisive factor in the proper use of these elements is the choice of a suitable joining method and the analysis of the joined members structural response. An experimental program to study five series of GFRP I-beams with different joint configurations subjected to transverse loading is described in the paper; the results of the tests will be compared in order to identify the most feasible method to join these structural elements.

Two methods utilized to improve the mechanical behaviour of the composite beams bolted joints are used in this experimental program.

For specimens consolidated with bonded aluminium inserts in holes the increase of bearing capacity is justified by the new surface created for transferring the load as well as the new transition area from a very rigid component to a weaker component.

There are only few experimental studies regarding this possibility of increasing the performance of FRP bolted joints. In a study performed by Camanho, (2005), the failure load increased with 24% when metallic inserts were bonded in holes for single lap composite joints and in a similar study conducted by Nilsson, (1989), the failure load increased with 30% for specimens with steel inserts and with 55% for specimens with aluminium inserts.

Adhesively bonded/bolted joint configurations minimize the characteristic weaknesses of the simple mechanical or adhesively bonded connection. The main function of bolts in hybrid systems is to prevent the peel stresses and to delay the failure initiation in the interface between adhesive and laminates.

An analysis of bolted/bonded single lap joints was performed by Barut & Madenci, (2009). Simulations have shown that most of load is transferred through the adhesive layer and when partial debonding is initiated the bolts start to take some of load and they resist the entire load when full debonding occurs.

Structural behaviour of double lap joints of steel splice plates bolted/bonded to pultruded hybrid CFRP/GFRP laminates was studied by Nguyen Duc Hai & Hiroshi Mutsuyoshi, (2012). They performed tensile and flexural tests on FRP plates and I-beams with bolted and bolted/bonded joints. It was concluded that the use of hybrid joints for beams subjected to flexural loading exhibited almost the same strength and stiffness as the control beam without joints. The stiffness of hybrid joints depends on the bonding strength and the failure mode and ultimate load of the joints governed by the number of bolts.

2. Specimens Design

Five series of I-120 × 6 – 2,000 mm GFRP pultruded beams with different joint configurations were prepared for the experimental program. The first series (S1) includes the control beams; the second series (S2) represents I-120 × 6 – 2,000 mm beams joined mechanically with steel bolts M10, grade 8.8. The joints were made using for web and flange GFRP plates with dimensions 240 × 90 × 6 mm, and 240 × 60 × 6 mm, respectively. The geometric characteristics of each series are presented in Figs. 1,...,5.

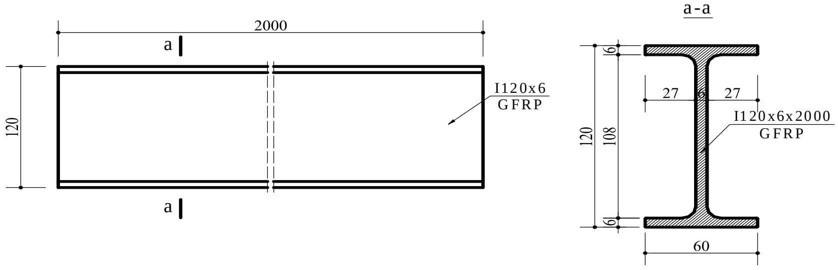

Fig. 1 – Specimens geometry for S1 series (dimensions in mm).

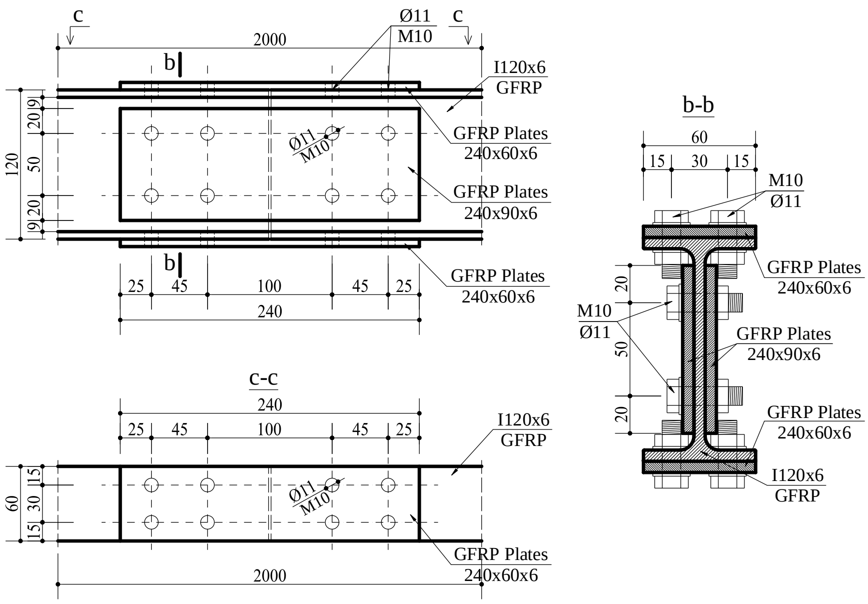

Fig. 2 – Specimens geometry for S2 series (dimensions in mm).

In case of the third series (S3), the beam specimens were joined mechanically using steel bolts M10 grade 8.8. and steel plates recommended by the producer of the GFRP profiles.

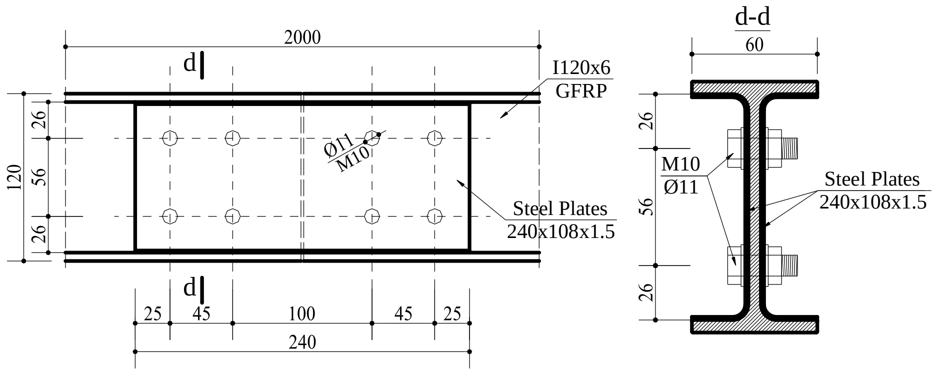

Fig. 3 – Specimens geometry for S3 series (dimensions in mm).

The fourth series (S4) contains specimens joined mechanically with consolidated holes using bonded aluminium inserts and finally the S5 series specimens have hybrid joints obtained by combining mechanically and adhesively methods.

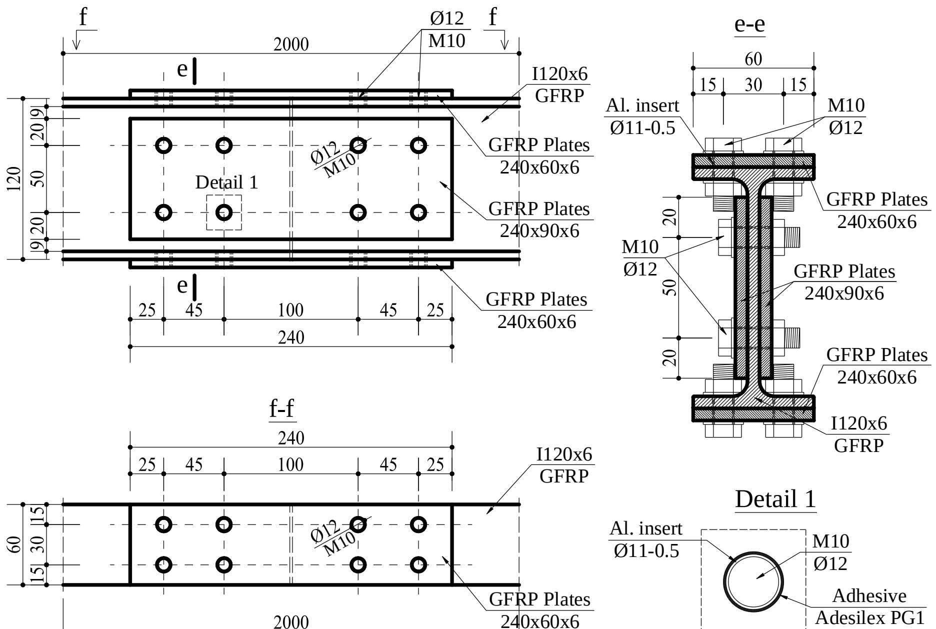

Fig. 4 – Specimens geometry for S4 series (dimensions in mm).

Pultruded profiles and plates are manufactured made of glass fibre reinforced polyesters with longitudinal reinforcement and mats on the transverse direction. The mechanical characteristics are presented in Table 1.

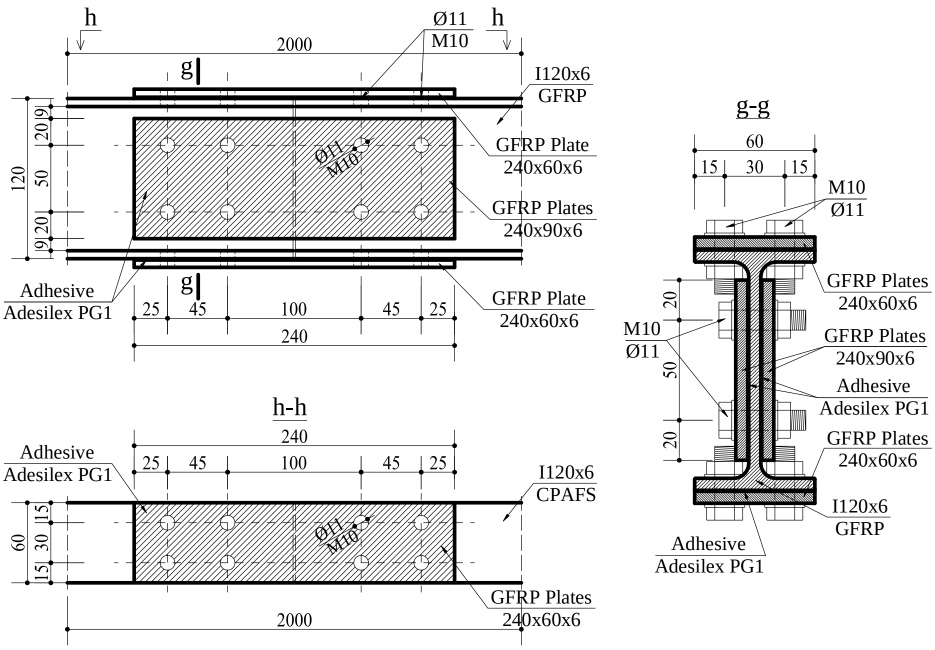

Fig. 5 – Specimens geometry for S5 series (dimensions in mm).

Table 1

Mechanical Characteristics for GFRP Profiles and Plates (Fiberline 2013)

Characteristics	GFRP profiles and plates
Modulus of elasticity, [GPa]	23
Tensile modulus – longitudinal, [GPa]	23
Tensile modulus – transverse, [GPa]	7
Bending strength – longitudinal, [MPa]	240
Bending strength – transverse, [MPa]	100
Tensile strength – longitudinal, [MPa]	240
Tensile strength – transverse, [MPa]	50
Compressive strength – longitudinal, [MPa]	240
Compressive strength – transverse, [MPa]	70
Pin-bearing strength longitudinal, [MPa]	150
Pin-bearing strength transverse, [MPa]	70
Shear strength – longitudinal, [MPa]	25

Beams and GFRP plates used for specimens were cut to size using a cutting machine equipped with diamond blade (Fig. 6). In the joint area, the elements were carefully cleaned and the excess of material from cutting was removed using a belt grinder for a better contact.

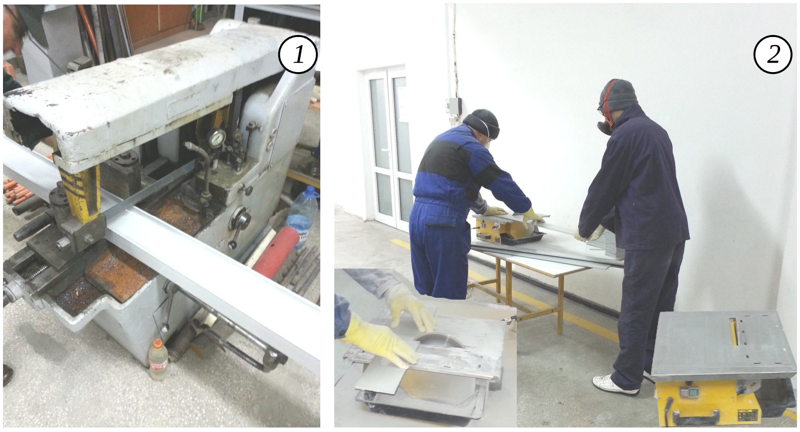

Fig. 6 – Specimens cutting: *1* – I-beams; *2* – plates.

To minimize defects that might occur in the process of drilling, four different types of drills were used at different rotation speeds. As it can be seen in Fig. 7 *a*, wood drill produced the lowest degradation. Drilling the holes in the specimens was performed in a fixed drill machine (Fig. 7 *b*) on low speed. The holes were drilled according to the prescriptions from norms, producing company and similar studies performed by I.S. Shyha *et al.*, (2009), and DeFu Liu *et al.*, (2012).

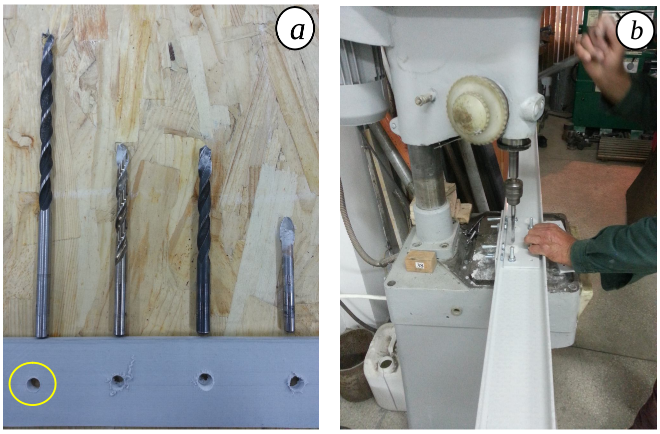

Fig. 7 – Specimens drilling: *a* – the type of drills utilized for holes; *b* – execution of holes in I-profiles and plates.

For S4 series specimens, the holes were carefully cleaned with acetone before bonding the aluminium inserts with 11 mm diameter and 0.5 mm thickness.

Adhesive (Adesilex PG1) used for bonding inserts and for hybrid joints (S5 series) is a bi-component product based on epoxy resins, selected fine-grain aggregates and special additives according to a formula developed by Mapei with mechanical characteristics presented in Table 2.

Table 2

Mechanical Characteristics for Adhesive Adesilex PG (Mapei, 2013)

Characteristics	Adesilex PG1
Mixing ratio	Component A : Component B = 3 : 1
Complete hardening time, [days]	7 days
Compressive modulus of elasticity, [N/mm^2]	6,000
Compressive strength, [N/mm^2]	70
Shear strength, [N/mm^2]	25

Adhesively bonded regions for S5 series required additional treatment in the joint region. The surfaces were cleaned with acetone, sanded with fine sandpaper to remove the coating and finally were cleaned again with acetone to obtain a good adherence.

3. Experimental Procedure

The testing of the specimens will be carried out in a 60 kN hydraulic testing machine (Fig. 7) with speed of testing set to a rate of crosshead movement 2 mm/min according to the provisions of ASTM D7264.

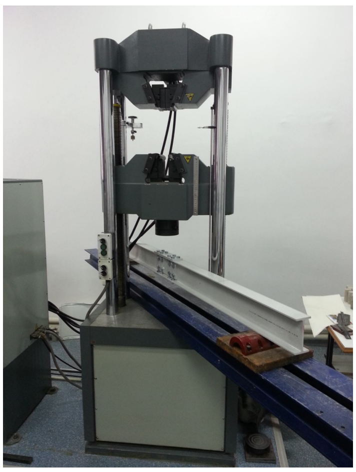

Fig. 7 – Testing machine.

The GFRP beams are simply supported subjected to a four point loading scheme (Fig. 8). The universal testing utilized to load the joined beams is equipped with a load cell and an acquisition board for data processing. The deflections are measured during the tests using integrated transducers from testing machine and for accuracy of results three linear variable differential transducers (LVDT) will be mounted at midspan and at 27.5 cm on each side.

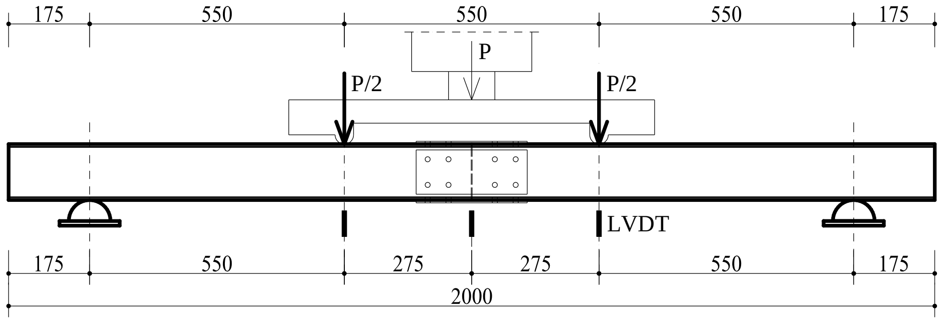

Fig. 8 – Position of load and LVDT's, (dimensions in mm).

The strains in the composite profiles and plates will be measured using strain gauges (SG) with two measuring grids T rosette and application on specimens will be performed in laboratory conditions respecting the indications given by appropriate norms (ASTM D-3039, ASTM D-5961).

4. Conclusions

An issue less studied in the area of structural composites beams is investigated in this paper. The designed experimental program enables the evaluation of the structural response of pultruded GFRP beams with different joint configurations subjected to flexure. The paper also describes the feasible methods of joining these structural elements.

Determining the failure strengths and ultimate deflections, identifying the failure modes, defects that may occur in execution as well as the advantages and disadvantages of joining methods for pultruded glass fibre reinforced polyesters I-beams are some of the results of this study.

It is expected that a significant increase of bearing capacity and stiffness for specimens with hybrid mechanical-adhesively joints and for beams with consolidated holes using bonded aluminium inserts will be achieved.

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RĂSPUNSUL STRUCTURAL AL GRINZILOR COMPOZITE FABRICATE DIN POLIESTERI ARMAȚI CU FIBRE DE STICLĂ ÎN DIFERITE IPOTEZE DE ÎMBINARE SUPUSE LA ÎNCOVOIERE. ORGANIZAREA EXPERIMENTULUI

(Rezumat)

Se descrie programul experimental cu privire la răspunsul structural al unor grinzi compozite fabricate prin pultrudere din poliesteri armați cu fibre de sticlă, supuse la incovoiere, în diferite variante de îmbinare. Programul cuprinde testarea a cinci serii de grinzi cu secțiunea I-120 × 6 mm şi lungimea de 2 m. Prima serie este constituită din grinzi de control fără îmbinare, a doua serie şi cea de-a treia sunt îmbinate mecanic în zona de mijloc cu plăci compozite şi metalice. Pentru seriile patru şi cinci au fost pregătite probe îmbinate mecanic cu şuruburi şi găuri consolidate prin lipirea unor inserții din aluminium, respectiv îmbinari hibride realizate prin combinarea metodei mecanice cu cea adezivă. Instrumentarea experimentului va permite observarea modului de comportare, a modurilor de cedare, determinarea forțelor şi deplasărilor la rupere.