BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 5, 2013
Secția
CONSTRUCȚII. ARHITECTURĂ

STRUCTURAL RESPONSE OF VARIOUS SINGLE LAP JOINT CONNECTIONS FOR PULTRUDED *E*-GLASS FIBRE RREINFORCED ISOPHTALIC POLYMERS COMPOSITE PLATES

BY

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Received: December 2, 2013
Accepted for publication: December 20, 2013

Abstract. The experimental results obtained from testing three joint configurations consisting of adhesively bonded, bolted, and hybrid joints with E-glass fibre reinforced isophthalic polyesters (GFRP) adherents are presented in this paper. The aim of this experimental program is to identify the failure modes, failure strengths and displacements for GFRP single lap joints using different joining methods. The best results have been obtained for hybrid joints manufactured by combining mechanical and adhesively bonded solutions. If compared with bolted joints, the results obtained for hybrid connections have shown an increase in the ultimate strength of 5% and 31% in comparison with adhesively bonded joints. For bolted joints with 10 Nm tightening torque, the values of the ultimate strength are 23% higher when compared with bolted joints without preloading, and approximately equal with the adhesively bonded joints.

Key words: bolted joints; adhesively bonded joints; hybrid joints; pultruded composites.

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1. Introduction

Experimental testing is the most accurate method used by researchers to determine the mechanical and elastic characteristics and to observe the behaviour of a material, element or structure. The specimen preparation and instrumentation with various transducers and strain gauges are very important in order to obtain a good quality of results.

Pultruded composite materials are increasingly used in civil engineering due to the exceptional mechanical characteristics, corrosion resistance and low maintenance during the life cycle.

The most common methods for joining pultruded plates and profiles are mechanical fastening and adhesive bonding.

In this study the experimental results, obtained by testing three different joint configurations (adhesively bonded, bolted, and hybrid) with adherents manufactured from GFRP and different overlap lengths are presented. The presented experimental results take into account the failure modes, strengths and displacements.

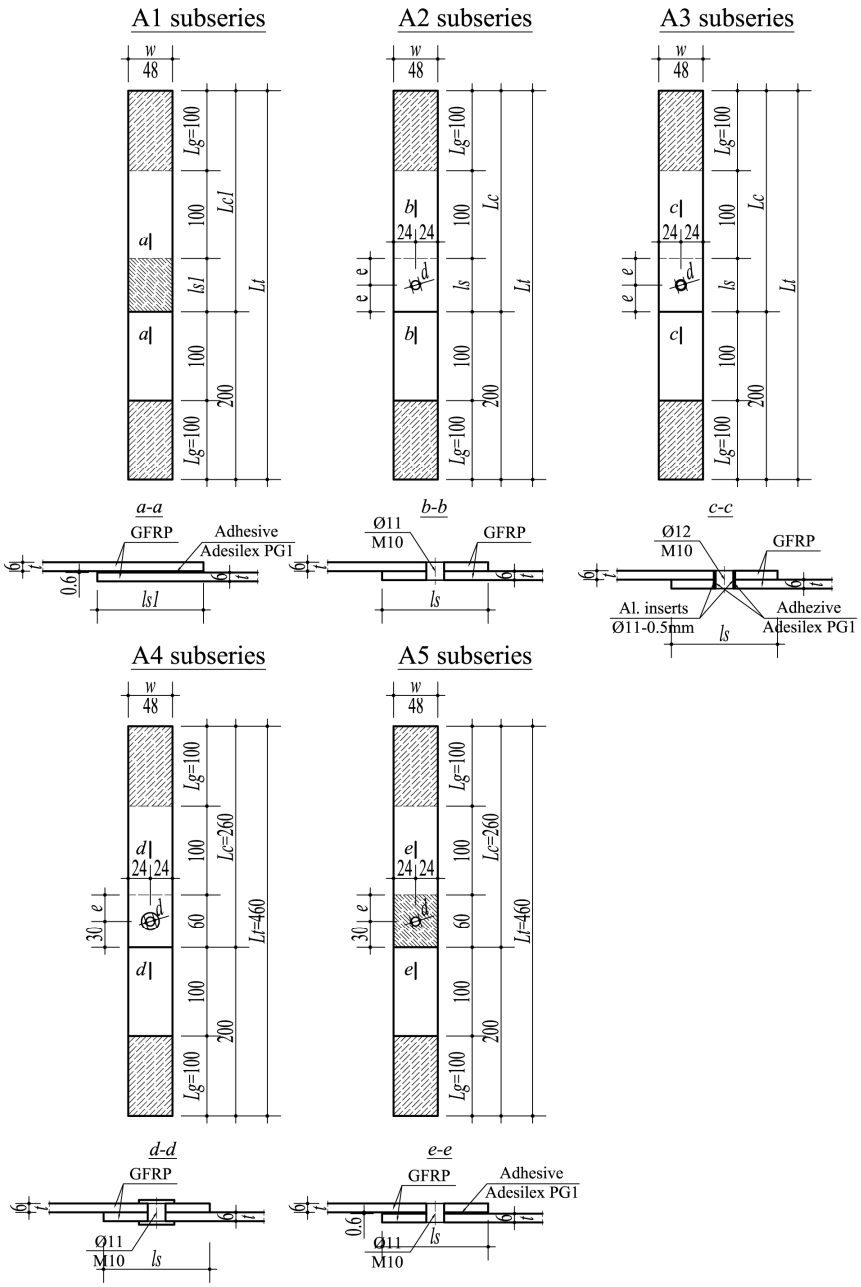
2. Experimental Program

This work is part of an extensive experimental program that is in progress at the Faculty of Civil Engineering and Building Services from Iaşi (Popoaei, 2012, 2013). In this part three different joint configurations (A Series) consisting of thirteen specimens with geometric characteristics described in Fig. 1, are presented.

The *A*-series consists of five subseries, *A*1...*A*5. The *A*1 subseries includes adhesively bonded joints with five different overlap lengths of 60,...,140 mm. The second and fourth subseries (*A*2...*A*4) have been combined using mechanical fastening method with steel bolts M10 gr. 8.8 with 0, 10, and, respectively, 20 Nm tightening torque. The third subseries are bolted joints with consolidated holes using bonded aluminium inserts of 11 mm diameter and 0.5 mm thickness. The *A*5 subseries consists of hybrid joints prepared by combining mechanical and adhesively bonded joining methods.

Pultruded adherents are manufactured from *E*-glass fibres reinforced isophthalic polyesters (GFRP) by Fiberline Denmark (Fiberline, 2013) and have been cut to size using a universal cutting machine. A machine tool equipped with wood drill and low rotation speed has been used for drilling holes in the plates in order to obtain a lower degradation of adherents.

The adhesively bonded joints regions and holes have been sanded with fine sand paper and cleaned with acetone for a better contact. The adhesive used for glued joints, bonded inserts and hybrid connections is a bi-component



- *Lc*/*Lc1* = 260, 280, 300 / 260, 280, 300, 320, 340 mm; *Lg* = 100mm; *Steel Bolts* M10 gr. 8.8;
- *Aluminum insets* Ø11-0.5mm; *Adhesive* Adesilex PG1; *t* = 6mm; *w* = 48mm; *w*/*d* = 5;
- *e*/*d* = 3,4,5 = 30,40,50mm; *d*/*t* = 1.67*; ls*/*ls1* = 60,80,100 / 60,80,100,120,140 mm (120,140mm);

Fig. 1 – Specimens geometry (dimensions in mm).

epoxy structural adhesive, Adesilex PG1, manufactured by Mapei Co. (Mapei, 2013).

To apply tightening torques on bolts, a torque indicator handle wrench has been used for good accuracy.

The tensile tests of the specimens have been performed in a 1,000 KN universal testing machine (Fig. 2). The speed of the test sample has been set at 2 mm/min. (crosshead movement) in accordance with ASTM D5868-01, D5961-13 and D6873-08.

The forces and displacements in the tested specimens have been measured using a load cell and linear variable differential transducers (LVDT).

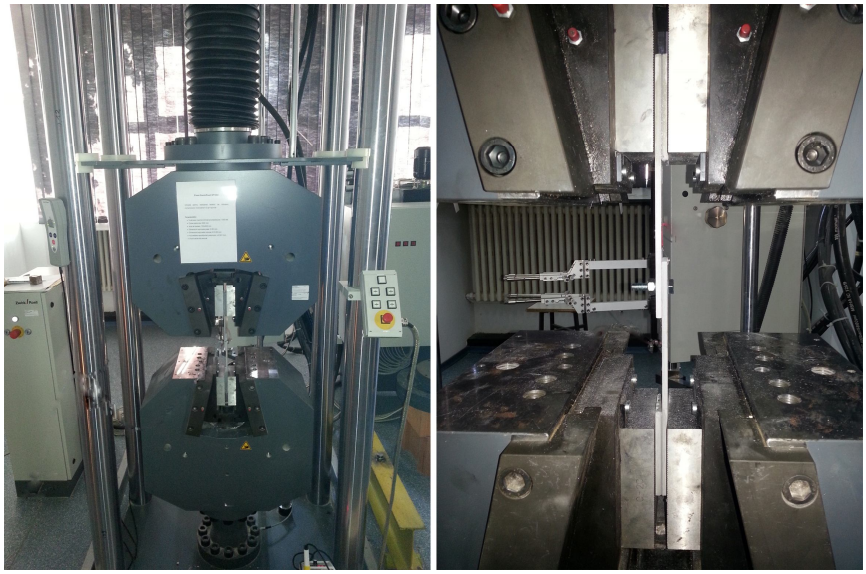


Fig. 2 – Universal testing machine and positioning of the specimens in turntables.

3. Experimental Results

Samples instrumentation allowed to monitor the forces and displacements during the tests and to observe the behaviour of these structural components.

3.1. Adhesively Bonded Joints

Five specimens with glued joints and different overlap lengths have been tested in this part of the experimental program. The failure modes identified during the tests occurred by the delamination of pultruded GFRP composite plates (separation of the first layer consisting of bi-directional

weaves) and the interface failure between the adherents and the adhesive layer (Fig. 3).

The best results have been obtained for specimens with 120 mm overlap length (A14), while the values for samples with 140 mm overlap length (A15) have shown an increase in the ultimate strength of just 4% in comparison with A14 samples.

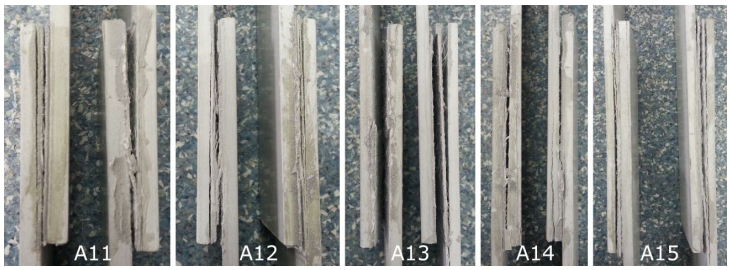


Fig. 3 – Failure modes for adhesively bonded joints.

The average force vs. displacements curves and the experimental results for each sample are presented. In Fig. 4 and Table 1.

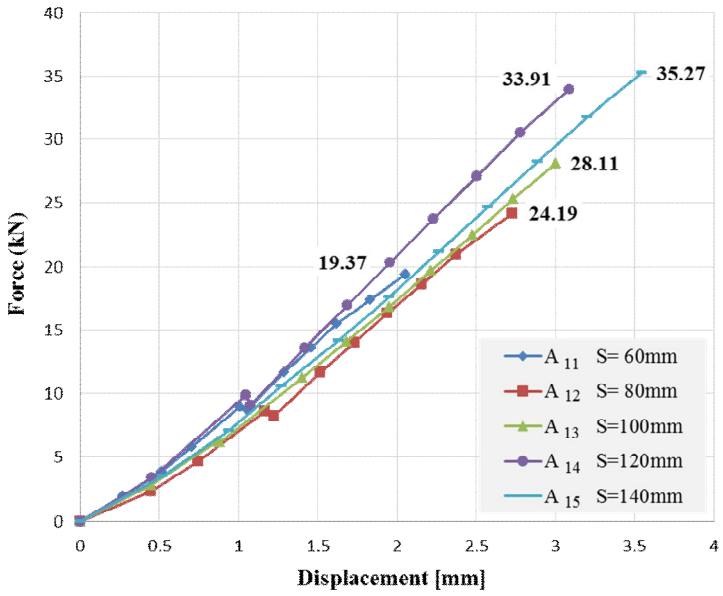


Fig. 4 – Force *vs.* displacement for adhesively bonded joints;
S – overlap length.

Table 1
Experimental Results for Adhesively Bonded Joints

Specimen	Maximum force, [KN]	Maximum displacement, [mm]
A11	19.37	2.04
A12	24.19	2.72
A13	28.11	3.00
A14	33.91	3.09
A15	35.27	3.55

3.2. Mechanical Joints with One Bolt

The *A*2 subseries consists of three joint configurations with 3, 4 and 5 bolt diameter (*d*) and edge distance (*e*). The failure modes identified for $e = 3d$ specimens are the shear out and for $e = 4d$ and $5d$ failure occurs by bolt pulling through the laminate (Fig. 5).

Fig. 5 – Failure modes for bolted joints.

The average force *vs*. displacement curves and the experimental data values for bolted joints specimens are presented in Fig. 6 and Table 2.

Table 2
Experimental Results for Bolted Joints

Specimen	Maximum force, [kN]	Maximum displacement, [mm]
*A*21	15.43	4.19
*A*22	18.76	6.44
*A*23	19.28	6.35

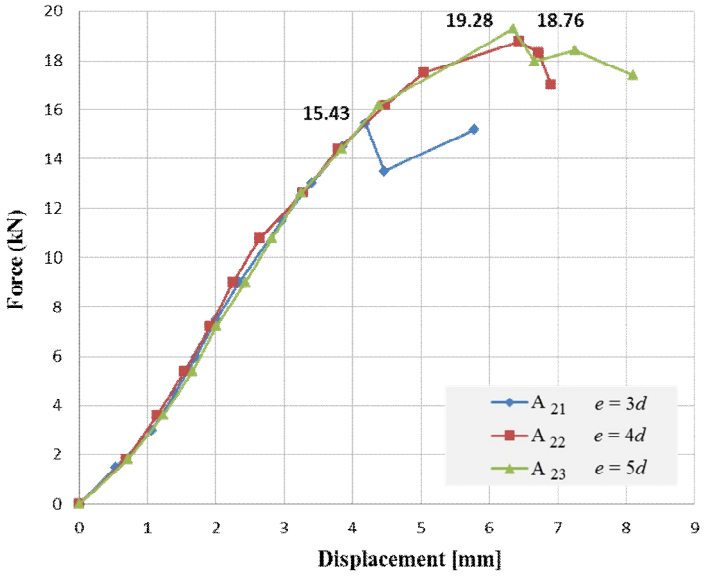


Fig. 6 – Force *vs.* displacement for bolted joints. *e* – edge distance; *d* – bolt diameter.

3.3. Bolted Joints with Bonded Inserts

For the bolted joints with bonded aluminum inserts the procedure has been similar to that of the *A*2 subseries, the identified failure modes have been shear out and the bolts pullout through laminates, identical with the *A*2 specimens (Fig. 7).

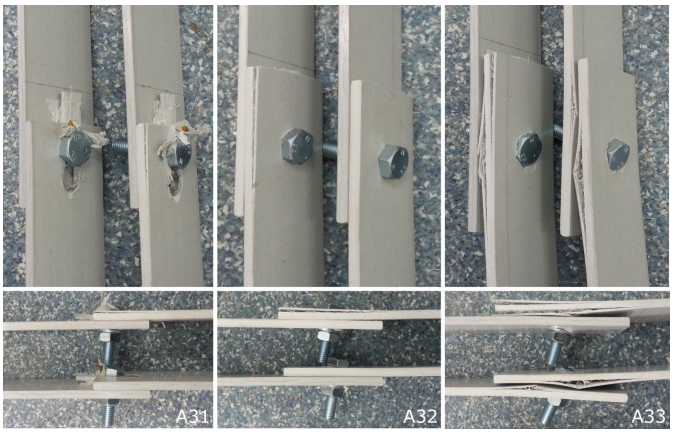


Fig. 7 – Failure modes for bolted joints with bonded inserts.

The experimental results presented in Table 3 have shown an insignificant difference in terms of failure strengths for the specimens with bonded inserts in comparison with the samples without inserts. Introducing bonded aluminum inserts in holes in case of the pultruded GFRP specimens with single lap single bolt joints is not a feasible method of improving the behaviour of these structural components.

Table 3
Experimental Results for Bolted Joints with Bonded Inserts

Specimen	Maximum force, [kN]	Maximum displacement, [mm]
A31	15.82	4.99
A32	17.80	8.02
A33	18.04	8.32

The force *vs*. displacement curves for the specimens with bonded inserts are presented in Fig. 8.

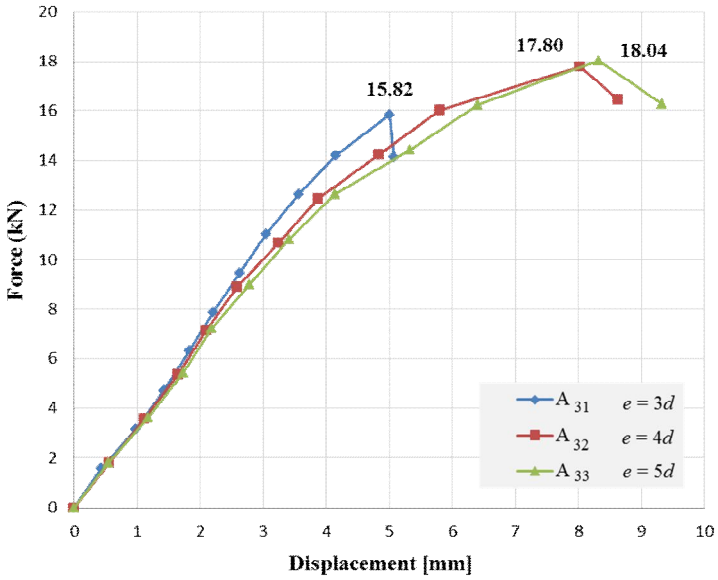


Fig. 8 – Force *vs*. displacement for bolted joints with bonded inserts; *e* – edge distance; *d* – bolt diameter.

3.4. Bolted Joints with Tightening Torque

For preloaded specimens two joints configurations with M = 10 Nm, M = = 20 Nm tightening torque and $e = 3d$ have been tested. The predominant failure mode observed in this case has been the shear out (Fig. 9).

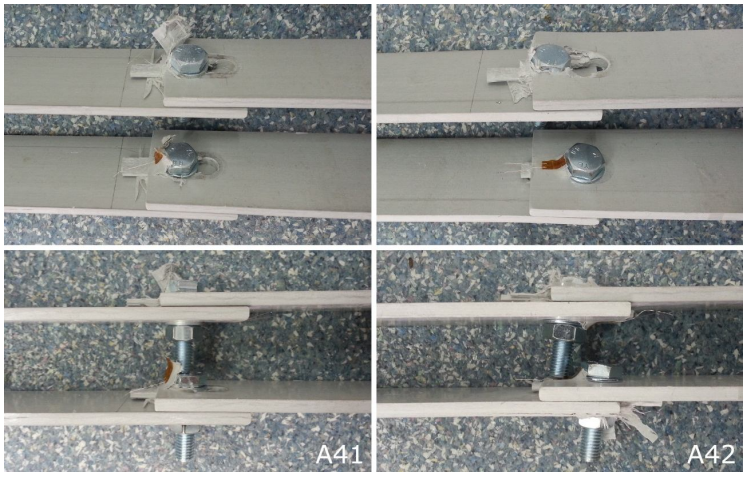


Fig. 9 – Failure modes for bolted joints with tightening torque.

The force *vs*. displacement curves have been plotted in the graph presented in Fig. 10. The better results have been obtained for specimens with 10 Nm tightening torque.

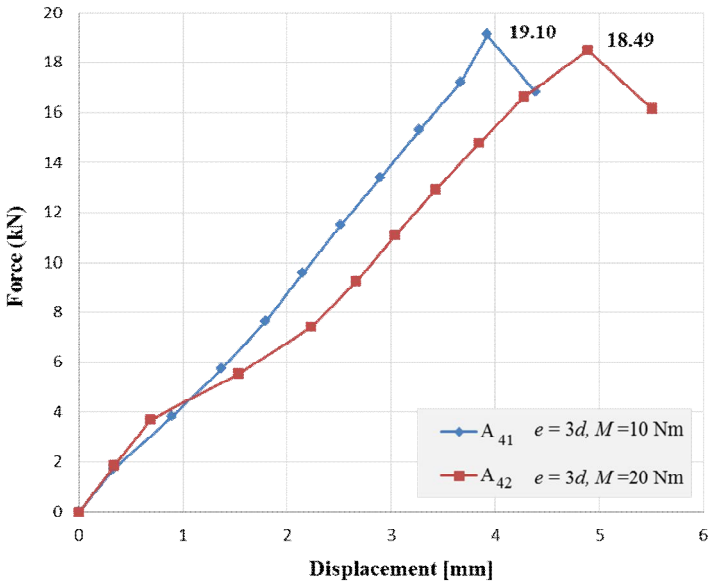


Fig. 10 – Force *vs*. displacement for bolted joints with tightening torque; *e* – edge distance; *d* – bolt diameter; *M* – torque.

The experimental values obtained for bolted joints with 10 Nm preload and $e = 3d$ and presented in Table 4, are obtained for bolted joints with 10 Nm preload and have shown an increase of 23.7% in terms of ultimate strengths in comparison with bolted joints without preload.

Table 4
Experimental Results for Bolted Joints with Tightening Torque

Specimen	Maximum force, [kN]	Maximum displacement, [mm]
A41	19.10	3.92
A42	18.49	4.89

3.5. Hybrid (Bolted/Bonded) Joints

The *A*5 subseries consists of specimens with hybrid joints manufactured by combining mechanical fastening and adhesively bonded methods. The hybrid configurations behave as adhesively bonded joints, and after the failure of the interface between the adhesive and the adherents or the adhesive failure the stresses are taken by bolts. In case of the *A*5 subseries (Fig. 11), the failure occurs by interface failure preceded by shear out or adherents delamination.

Fig. 11 – Failure modes for hybrid joints (bolted/bonded).

The force *vs*. displacement average curve and the experimental data values are presented in Fig. 12 and Table 5. The experimental results have shown an increase in the ultimate strengths for hybrid joints of 65% in comparison with the bolted connections, and of 31% when compared with the adhesively bonded joints.

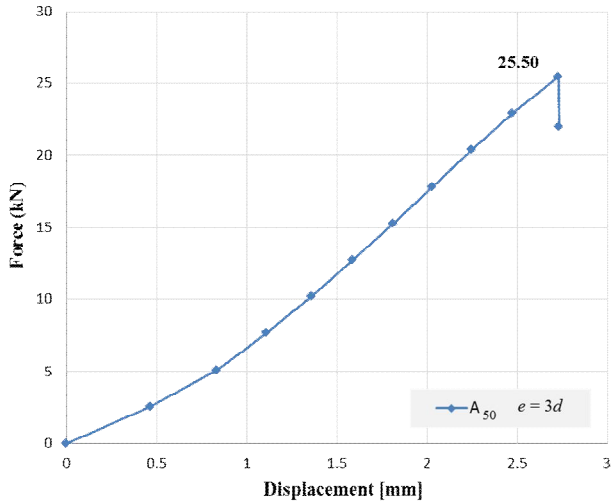


Fig. 12 – Force *vs*. displacement for hybrid (bolted/bonded);
e – edge distance; *d* – bolt diameter.

Table 5
Experimental Results for Hybrid Joints (Bolted/Bonded)

Specimen	Maximum force, [kN]	Maximum displacement, [mm]
A50	25.50	2.73

4. Conclusions

The structural response regarding the behaviour of single lap joints with pultruded glass fibre reinforced isophthalic polyesters adherents has been investigated in this paper. The most common methods used for joining composite materials such as adhesively bonding and mechanical fastening, have been experimentally analysed.

Specimens with preloaded bolts, bonded inserts and hybrid connections have been tested in order to improve the performance of the pultruded GFRP single lap joints.

In the case of the adhesively bonded joints the best results have been obtained for specimens with 120 mm (2.5 × width) overlap length. If compared with the bolted joints, the results obtained for glued connections have shown an increase in the ultimate strength of 25% and a decrease of 31% in comparison with the hybrid joints.

The experimental results have shown an insignificant difference in terms of failure strengths and displacements for specimens with bonded aluminum inserts in comparison with the samples without inserts. Therefore it can be concluded that this method is not feasible for the pultruded GFRP single lap single bolt joints.

The best results have been obtained for specimens with hybrid and preloaded joints. The results obtained for bolted joints with 10 Nm tightening torque are 23% higher than those with non-preloaded connections. If compared with the bolted joints, the values of the hybrid joints have shown an increase in the ultimate strengths of 65% and a decrease in the ultimate displacements of 53%.

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RĂSPUNSUL STRUCTURAL AL UNOR ÎMBINĂRI PRIN SUPRAPUNERE SIMPLĂ LA PLĂCI PULTRUDATE COMPOZITE DIN CPAFS

(Rezumat)

Sunt prezentate rezultatele experimentale obținute în urma testării a trei configurații de îmbinare compuse din îmbinări lipite cu adezivi, mecanice şi hibride, cu aderenți din poliesteri isoftalici armați cu fibre de sticla tip *E* (CPAFS). Scopul acestui program experimental este de a identifica modurile de cedare, forțele şi deplasările la rupere la CPAFS îmbinate prin diferite metode. Rezultatele cele mai bune au fost obținute pentru îmbinările hibride, realizate prin combinarea metodei adezive cu cea mecanică. Dacă sunt comparate cu îmbinările mecanice, rezultatele obținute pentru îmbinările hibride indică o creştere cu 65% a forței ultime şi cu 31% în comparație cu îmbinările lipite cu adezivi. Pentru îmbinările mecanice cu 10 N.m moment de strângere aplicat şuruburilor, valorile forțelor ultime sunt cu 23% mai mari decât la îmbinările fără moment de strângere şi aproximativ egale cu rezultatele îmbinărilor adezive.