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Flexural Properties of Hybrid Composite Parts

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Abstract: The aim of this work was to determine the flexural properties of hybrid composites parts cut from trapezoidal core made of carbon/glass fibers impregnated in epoxy resin with help of filament winding technology. Values for stress, strain and module of elasticity were calculated using three point bending test. The tests were performed according to American Society for Testing and Materials (ASTM) standards. Hybrid fiber reinforced plastic (FRP) laminates exhibit progressive failure consisting of fiber failure, debonding, and delamination.

Further, the paper investigates the content of voids inside the structure, the interface fiber/epoxy resin using scanning electron microscope and the procedures involved in the laminate design, fabrication, experiments and analysis of composite part for decks.

Key words: hybrid composites, three point bending test, filament winding.

Introduction

In civil work construction, composite materials show their advantages in comparison to traditional ones, steel and concrete, due to their low weight, higher corrosion resistance especially in the marine environment, and ease of installation, which significantly reduce maintenance and replacement costs. Decks for both pedestrian and vehicle bridges across waterways, railways and roadways are now a commercial reality in both North America and Europe, with some pedestrian bridges being built entirely from composites (Gorrochategui et al. 2012; Fiber Span Decking, 2013). Composed of hexagon and double-trapezoid profiles, bridge deck sections are bonded with high-strength adhesive under controlled conditions to create a load transfer mechanism between the components. In essence, composite durability not only improves life-cycle costs, but extends the life-cycle itself (Hastak, 2003; Li et al., 2010).

In this study, flexural properties of composite samples cut from hybrid trapezoidal part is presented. Samples are characterized with significant amount of voids, due to the specific winding process that has been conducted for trapezoid production. Failure and delamination mechanisms are also described.

Materials and methods

For hybrid sample production four bobbins carbon fiber T700S 12K from Toray and five bobbins E-glass roving P185 1200tex from Owens Corning were used. Mentioned reinforcements were impregnated in epoxy resin system Araldite LY564/Aradur 917/Accelerator 960-1 from Huntsman. Winding process was conducted on rotating collapsible trapezoidal mandrel with pins on both sides with help of laboratory filament winding (FW) machine MAW FB 6/1 with six axes, mechanical creel and roller type resin bath manufactured from Mikrosam A.D. Calculated mass fraction of matrix in final composite part was 32 w%, with mass ratio between glass and carbon fibers 30:38 w%, respectively. Finally, hybrid trapezoid part was manufactured with 32 layers with following design, where with index “c” carbon fibers and “g” E-glass fibers are marked $[90_c/0_{2c}/90_c/(0_{2c}/90_{2c}/45_{2c}/90_{2g}/0_{2g}/90_{2g}/45_g)_s/90_{2c}]$. Small angles were used for production of hybrid trapezoid part, due to their benefits to the mechanical properties (Sideridis and Papadopoulos, 2004; Belingardi et al., 2006; Risteska et al., 2014).

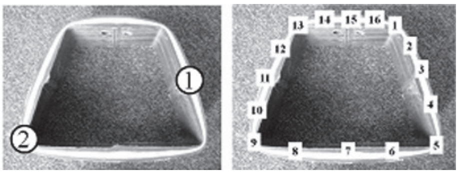


Figure 1. Cross section of hybrid trapezoid composite part
(a) different thickness of walls, (b) places for void measurement

Different amount of applied tension during winding, due to specific form of the mandrel caused difference in wall thickness on trapezoid side's and corner's (Fig. 1a). It was assumed that trapezoid corners have no voids, whereas voids are present on trapezoid sides. To determine the amount of voids in the final trapezoid part, samples were cut from different places marked with numbers from 1 to 16 on the structure (Fig.1b).

Void content in the composite was determined with help of experimental (ρ_e) and theoretical density (ρ_t) of composite according to ASTM D3171 (ASTM International, 2011) and method A from ASTM D792 (ASTM International, 2013) standards, respectively.

To determine the influence of voids on mechanical properties of produced hybrid composite part from both bases of trapezoidal core seven rectangular forms were cut and tested on three point bending test. Samples were prepared according to ISO 14125 standard with span-to-width ratio of 10 (ISO, 1998). Values of specimen's dimensions are given in Table 1. Tests were performed on computer controlled universal testing machine from Shimadzu with maximal load of 250 N.

Table 1: Dimensions of specimens.

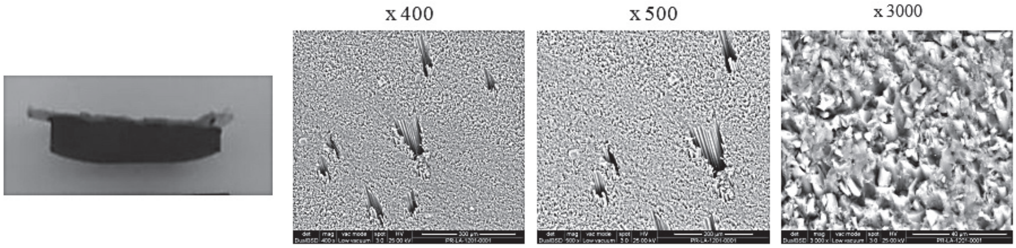
N^o	L_o (mm)	l (mm)	h (mm)	b (mm)
1	400	300	20.2	30.1
2	400	300	20.3	30.3
3	400	300	22.4	30.1
4	400	300	22.5	29.5
5	400	300	22.3	30.4
6	400	300	21.2	30.1
7	400	300	22.5	30.1

Results and Discussion

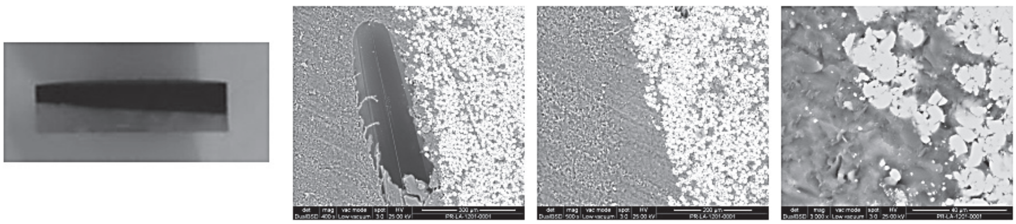
Calculated void's values of 5.5 % and 1.5 % in trapezoid sides and corners are given in Table 2. From completed calculations for experimental and theoretical density it was remarked, that corner's density is higher in comparison to the density of trapezoid's sides, which leaded to more than three times lower voids content in trapezoid corners. It is presumed, that during production process winding tension is smaller on trapezoid sides, which promote delamination when smaller winding angles (0^o) were winded. Because, winding tension has shown more pronounced effect on trapezoid corners, the excess amount of resin has been removed from the structure, which resulted in a significant decrease of resin's weight percent on the corners. Voids formation and influence in composite structures has been reported in (Huber, 1996; Risteska et al., 2014; Dorigato and Pegoretti, 2014).

Table 2. Void content in hybrid composite part.

Trapezoid's	$\rho_{e.mid}$ (g/cm^3)	$\rho_{t.mid}$ (g/cm^3)	void$_{mid}$ (%)
side	1.68	1.77	5.5
corner	2.08	2.12	1.5

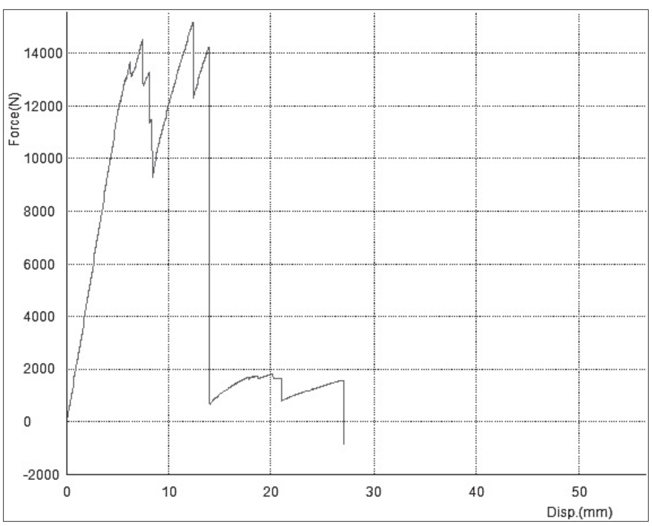


a) Void size 75.04µm



Void size 553.07µm

Figure 2. SEM images



Also, voids were detected in the cross section of the hybrid structure sides (Fig. 2). SEM images with different magnification were taken from the side of manufactured sample, where good adhesion between reinforcements and resin can be seen. On Fig. 3 is shown characteristic force-deflection (F-d) diagram which was received directly through the plotter during flexural test of sample N° 3. Load-displacement curves were plotted for every sample and afterwards values for stress, strain and module of elasticity were calculated.

Figure 3. Force - Defflection diagram of specimen N°3

Flexural stress, σ_f in the outer surface of the test specimens occurred at the midpoint. These stresses were determined from the relationship:

$$\sigma_f = \frac{3FL}{2bh^2} \qquad (1)$$

In (1), σ_f is the flexural stress in MPa, F is the load in N, L is the support span in mm, b is the width in mm of specimen tested, and h is the thickness of specimen tested in mm.

Flexural modulus of elasticity is calculated according to (2):

$$E_f = \frac{L^3}{4bh^3}\left(\frac{\Delta F}{\Delta s}\right) \qquad (2)$$

Where, E_f is the flexural modulus of elasticity in MPa, Δs is the difference between specimen mid-point deflections in mm, ΔF is the load difference in specimen mid-point deflections in N.

Flexural strain, ε_f of hybrid composite specimens was determinate using the fallowing equation:

$$\varepsilon_f = \frac{6sh}{L^2} \qquad (3)$$

Table 3. Flexural properties of hybrid specimens.

N°	s_0 (mm)	s (mm)	F_0 (N)	F_{max} (N)	ε (-)	E (GPa)	$σ_f$ (MPa)	τ (MPa)
1	8.0	12.2	11200	13400	0.024	38.1	490.9	16.5
2	8.5	9.0	13500	14000	0.018	41.9	501.2	17.0
3	7.0	9.5	11000	14500	0.019	31.4	432.7	16.1
4	5.0	5.0	9000	12000	0.010	35.8	359.4	13.5
5	7.0	7.0	12000	12800	0.014	34.3	381.0	14.2
6	8.0	15.0	11000	12500	0.030	32.4	415.8	14.7
7	8.0	9.0	10500	14000	0.018	25.8	413.4	15.5

In (3) $ε_f$ is the strain in the outer surface in mm/mm, s is the maximum deflection of the center of the composite specimen in mm, h is the thickness of the specimen in mm and L is support span length in mm.

In Table 3 are given the results for stress, strain and modulus of elasticity calculated from received diagrams, whereas first ply failure (FPF) occur around 11000 N flexural force.

In addition, images of three point bending tests are shown in Fig. 4. In all samples, failure of outside carbon fiber layer has been detected, due to fracture under the center load followed by interlaminar shear failure at the interface between E-glass fiber and carbon fibers layers. The place of critical failure is related with the presence of voids. Crack propagation leads through the inner E-glass layers of composite samples which caused delamination, as dominant fracture mechanism. Consequently, hybrid sample cannot further endure the load and it breaks.

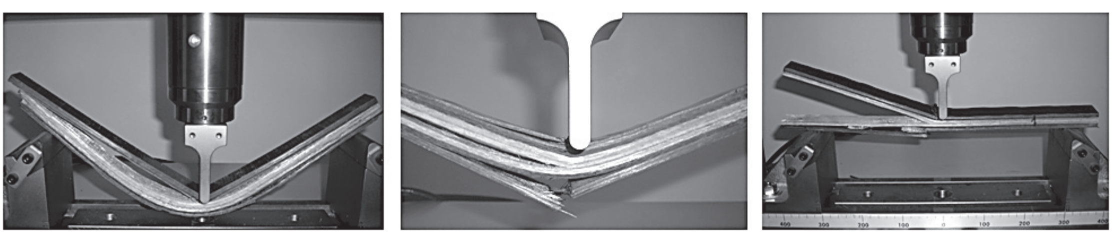


Figure 4. Three point bending tests of hybrid composite specimens.

Flexural strength of hybrid samples has been reported in (Bumpus, 2002; Dong et al., 2012; Lim et al., 2014). Flexural properties of hybrid unidirectional fibre reinforced polymer (FRP) composites with span to depth (S/d) ratios of 16, 32, and 64 are investigated in (Davies and Hamada, 2001; Sudarisman and Davies, 2008). Flexural characteristic of glass fiber reinforced composite decks of triangular, trapezoidal and rectangular shape have been studied in (Lee et al., 2005), where filament winding technique is considered as advantageous deck manufacturing method, due to the easy fabrication for both straight and curved portion of bridge deck with inexpensive die.

According to the received results, it can be concluded that voids presence in composite structure show negative effect on maximal flexural stress. Void percent in final composite structure can be reduced if some contact method or higher winding tension are used during sample fabrication. This will decline sample delamination which is consequence of smaller angles winding and use of pins on both sides of the mandrel.

Mathematical model of the influence of the parameters on the content of voids in trapezoidal beams will be present in future.

Conclusion

A study of flexural properties of hybrid composite samples made of carbon and glass fibers impregnated in epoxy resin manufactured with help of FW technology is presented in this article. Even though filament winding tension was constant during the winding process, it wasn't evenly distributed on trapezoid mandrel, due to it specific form. This caused different thickness and quantity of voids in specimen walls and corners.

The experimental work show that specifically chosen filament winding design have significant load bearing qualities and elongation with delamination as dominant fracture mechanism. Maximal flexural properties of 501.2 MPa are reached when void percent in the sample is around 1.5 %, whereas void percent of 5.5 % decrease flexural strength to 359.4 MPa.

SEM analysis present good merger between reinforcements and the matrix, showing that hybrid composite samples with good quality has been manufactured.

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