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ON THE STIFFNESS INCREASE OF FIBRE-REINFORCED COMPOSITE STRUCTURES

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Abstract: *The paper presents theoretical and experimental approaches regarding the stiffness increase of fibre-reinforced composite structures with application to a sandwich which presents the following plies sequence: 1 x RT500 glass roving fabric/ 2 x RT800 glass roving fabric/ 1 x 450 g/m^2 chopped glass fibres mat/ nonwoven polyester mat as core/ 1 x 450 g/m^2 chopped glass fibres mat/ gelcoat layer. The sandwich structure manufactured at COMPOZITE Ltd., Brasov, Romania is formed of twelve curved shells and presents dissimilar skins. Three-point bend tests have been carried out to determine the most important features of this structure, as well as a finite element analysis. Stresses and strains have been measured using strain gauges applied on a curved shell subjected to bending. The experimental researches accomplished on specimens manufactured from the same material as the structure present a twelve times increase of the flexural rigidity against the upper skin one.*
Keywords : *sandwich, core, skin, stiffness, flexural rigidity*

1. INTRODUCTION

The stiffness increase of a fibre-reinforced composite structure is obtained through “thickenning” the composite structure with a low density core material [1-6]. The purpose of this “thickening” is to obtain a substantial increase of the flexural rigidity of the whole structure, without a significant increase in its entire weight [7-13]. Sandwich structures are more and more used in various applications due to their high stiffness at bending. Nowadays, there are a great variety of cores such as rigid foams, hexagonal structures made from thermplastics, metallic and non-metallic materials, expandable and fireproof materials, balsa wood, etc., [8-16]. In general, composite laminates are formed by thin layers called laminae. These laminates present a quite low stiffness and flexural rigidity. A solution could be their stiffening using ribs [17], [18]. However, there are constructive situations when these ribs can not be used [19-21]. Another solution could be the increase of layers number that compose the structure. But this solution presents the disadvantage of the increase of resin and reinforcement consumption with economic and environmental consequences.

2. THE STRUCTURE

In order to avoid the previously presented disadvantages, a sandwich structure has been manufactured at Compozite Ltd., Brasov, Romania (fig. 1). The sandwich structure is composed from the following layers:

- 1 x RT500 glass roving fabric;
- 2 x RT800 glass roving fabric;
- 1 x 450 g/m^2 chopped glass fibres mat;
- A nonwoven polyester mat as core;
- 1 x 450 g/m^2 chopped glass fibres mat;
- A gelcoat layer.

The core presents the most important influence in the overall structure’s stiffness and flexural rigidity. Its material is a random oriented noncontinuous nonwoven polyester mat which contains microspheres that prevent excessive resin consumption. The most important features of the whole structure using this kind of core are:

- Stiffness increase;

- Weight saving;
- Resin and reinforcement saving;
- Fast build of the structure’s thickness;
- Superior surface finish.

Figure 1: Zoomed cross section of the sandwich structure

The nonwoven polyester mat is soft, present excellent resin impregnation and high drapeability when it is wet and therefore is suitable for complex shapes. It is most often applied against the “gelcoat” to create a superior surface finish for instance on hull sides. The applying of the nonwoven polyester mat against the “gelcoat” layer is more important when dark “gelcoats” are used, to prevent the appearance of the glass fibres reinforcement. This material has a good compatibility with the polyster, vinylester and epoxy resins and is suitable for hand lay-up and spray-up processes.
This plies sequence has been used to manufacture a spherical cap structure at Compozite Ltd., Brasov, Romania (fig. 2) formed by twelve curved shells.

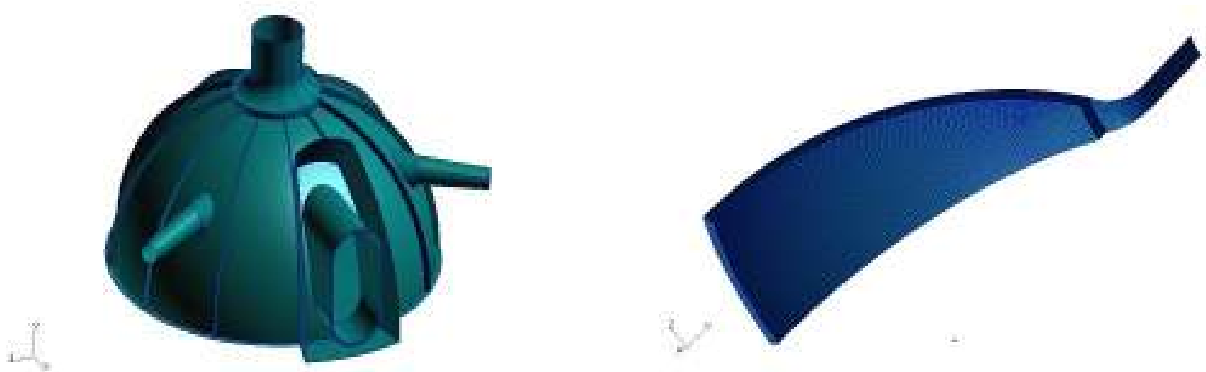

Figure 2: spherical cap sandwich structure formed by twelve curved shells

3. THE FLEXURAL RIGIDITY EVALUATION

According to the ordinary beam theory, the flexural rigidity, here denoted R, of a beam is the product between Young modulus of elasticity *E* and the moment of inertia *I* (that depends on structure’s cross-section). The flexural rigidity of an open sandwich beam assumed to have thin skins of equal thickness represents the sum between the flexural rigidities of the skins and core determined about the centroidal axis of the whole cross section (fig. 3) [1]:

$$R = E_s \cdot \frac{b \cdot t^3}{6} + E_s \cdot \frac{b \cdot t \cdot d^2}{2} + E_c \cdot \frac{b \cdot c^3}{12}, \quad \textbf{(1)}$$

where E_s and E_c represent the Young moduli of elasticity for skins and core respectively.

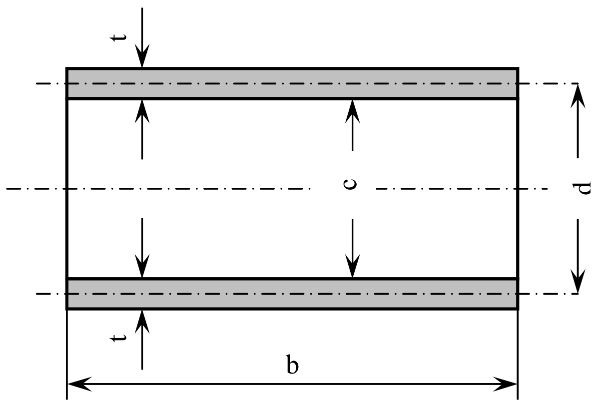

Figure 3: Dimensions in a cross section of an open sandwich beam with equal thickness skins

If the skins present different materials and unequal thickness, like our structure with dissimilar skins (fig. 4) and taking into consideration that the local flexural rigidities for the skins can not be neglected, which means that [1]:

$$\frac{d}{t} > 5.77, \quad \textbf{(2)}$$

the sandwich flexural rigidity can be written according to reference [1] as:

$$R = \frac{b \cdot d^2 \cdot E_{s1} \cdot E_{s2} \cdot t_1 \cdot t_2}{\left(E_{s1} \cdot t_1 + E_{s2} \cdot t_2\right)} + \frac{b}{12} \cdot \left(E_{s1} \cdot t_1^3 + E_{s2} \cdot t_2^3\right). \quad \textbf{(3)}$$

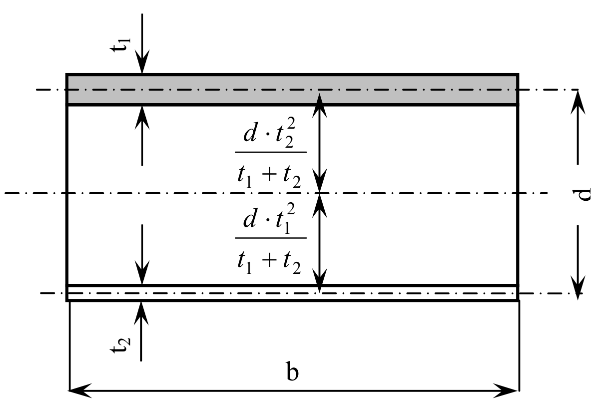

Figure 4: Dimensions in a cross section of an open sandwich beam with dissimilar skins

Considering the beam as a wide one, the structure's flexural rigidity can be computed as follows:

$$R = \frac{b \cdot d^2 \cdot E_{s1} \cdot E_{s2} \cdot t_1 \cdot t_2}{\left[E_{s1} \cdot t_1 \cdot (1 - \upsilon_{s2}^2) + E_{s2} \cdot t_2 \cdot (1 - \upsilon_{s1}^2)\right]} + \frac{b}{12} \cdot \left(\frac{E_{s1} \cdot t_1^3}{1 - \upsilon_{s1}^2} + \frac{E_{s2} \cdot t_2^3}{1 - \upsilon_{s2}^2}\right), \quad \textbf{(4)}$$

where the suffixes 1 and 2 refer to the upper and lower skins respectively, b represent the width of the beam cross section, d is the distance between centrelines of opposite skins, t is the skin thickness, c is the core thickness, υ_{s1} and υ_{s2} represent the upper respective the lower skin Poisson ratio. In case that we consider the structure as a sandwich panel supported on two sides, this panel can be seen as a wide open beam. Condition (2) remains the same but in flexural rigidity analysis, due to the fact that each skin is considered a thin plate, the ratio between stress and strain is $\frac{E}{1 - \upsilon^2}$, see for instance [1].

4. RESULTS OF THREE-POINT BEND TESTS

The three-point bend test has been used to determine the most important features of this test. Twelve specimens have been cut from a sandwich panel and subjected to bending until break occurs. Some specimens characteristics are presented in table 1. The test features are presented in table 2.

Table 1: Specimens features

Average dimensions	Value
Width, b (mm)	15
Length (mm)	150
Sandwich thickness (mm)	8.27
Core thickness, c (mm)	4
Cross-section area (mm^2)	124.05
Thickness of the upper skin, t_1 (mm)	3.1
Thickness of the lower skin, t_2 (mm)	1.1
Distance, d (mm)	6.17

Table 2: Test characteristics

	Value
Test type: three-point bend	-
Test speed (mm/min)	4
Span (mm)	130

The tests have been carried out on a LR5K-type testing machine (5 kN maximum load) as well as on a Texture Analyser type TA (1 kN maximum load), produced by Lloyd's Instruments. The following features have been determined using the software NEXYGEN-plus:

- Stiffness;
- Young modulus of bending;
- Flexural rigidity;
- Load at maximum load;
- Maximum bending stress at max. load;
- Machine extension at maximum load;
- Extension at maximum load;
- Maximum bending strain at maximum load;
- Work at maximum load;
- Load at maximum extension;
- Maximum bending stress at max. extension;
- Machine extension at max. extension;
- Extension at maximum extension;
- Maximum bending strain at max. extension;
- Work to maximum extension;
- Load at minimum load;
- Maximum bending stress at min. load;
- Machine extension at minimum load;
- Extension at minimum load;
- Maximum bending strain at minimum load;
- Work to minimum load;
- Load at minimum extension;
- Maximum bending stress at minimum extension;
- Machine extension at minimum extension;
- Extension at minimum extension;
- Maximum bending strain at minimum extension;
- Work to minimum extension;
- Load at break;
- Maximum bending stress at break;
- Machine extension at break;

- Extension at break;
- Maximum bending strain at break;
- Work to break.

The input data for the theoretical approach are presented in table 3. Some experimental results obtained on twelve sandwich specimens are presented in figs. 5 and 6.

Table 3: Input data

	Value
Young modulus of bending, E_{s1} (MPa)	6118.6
Young modulus of bending, E_{s2} (MPa)	7172.6
Upper skin Poisson ratio, υ_{s1} (-)	0.25
Lower skin Poisson ratio, υ_{s2} (-)	0.35

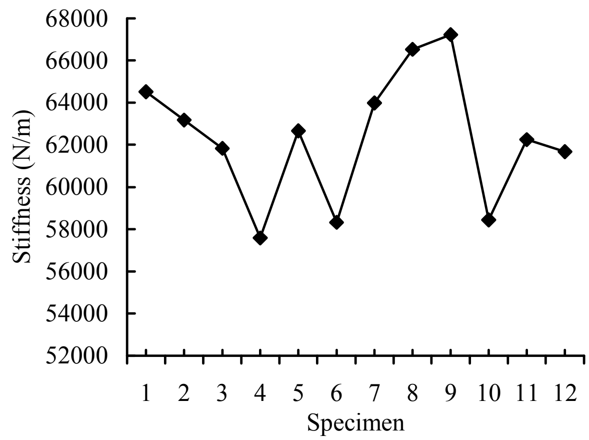

Figure 5: Stiffness distribution of twelve specimens

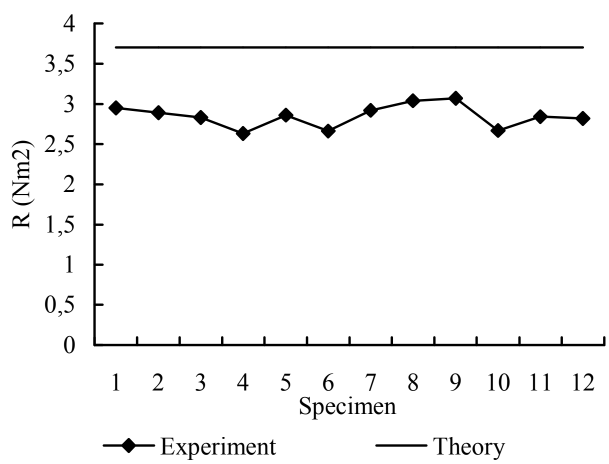

Figure 6: Flexural rigidity distribution of twelve specimens. Comparison with theoretical approach

5. CONCLUSIONS

The sandwich structure with thin nonwoven polyester mat as core presents an excellent bond between skins and core. This has been noticed during the three-point bend tests. The sandwich structure's flexural rigidity determined experimentally is twelve times grater than the upper skin's one, 57 times grater than the core's one and more than 237 times grater than the lower skin's flexural rigidity (fig. 7). The 30% difference in structure's flexural rigidity determined theoretically and the experimental approach can be a little bit reduced by a better estimation of the upper and lower skin's Poisson ratios.

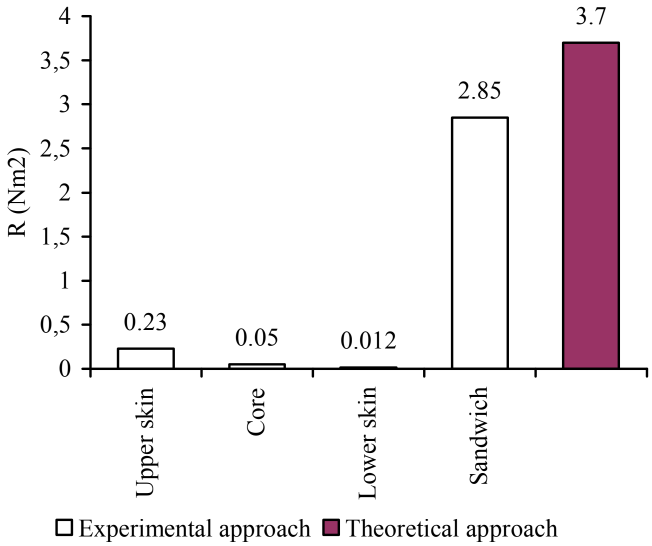

Figure 7: Sandwich structure's flexural rigidity evaluation

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