Engineering Letters, 18:3, EL_18_3_08

Thermomechanical Response of a Thin Sandwich Composite Structure

Horatiu Teodorescu-Draghicescu, Sorin Vlase, Dana Luca Motoc, and Anghel Chiru

Abstract—**The paper presents a stiffness evaluation as well as thermal response of a sandwich structure with thin nonwoven polyester mat as core. The structure presents dissimilar skins from which one is a glass fabric reinforced polyester. Tensile and three-point bend tests have been carried out to determine the most important features of this structure. The thermal expansions have been measured using a DIL 420 PC dilatometer from NETZSCH, on both glass fabric reinforced polyester skin and for the whole structure. The coefficients of thermal expansion have been determined only for the structure's upper skin. For each sample, two successive heating stages in order to size the influence of the thermal cycling, and temperature interval from 20^0C to 250^0C, at a heating rate of 1 K/min have been used. To eliminate the system errors, the dilatometer has been calibrated by measuring a standard SiO_2 specimen under identical conditions. The experimental researches accomplished on specimens show a twelve times increase of the flexural rigidity against the upper skin one.**

Index Terms—**Core, sandwich, stiffness, thermal expansion.**

I. INTRODUCTION

In general, a sandwich structure is manufactured of three layers: two cover layers called "skins", that form the carrying structure, layers composed of stiff and resistant material, and an intermediate layer named "core", which has the main purpose to sustain the skins and to give stiffness to whole structure [1]–[6]. This stiffness is obtained actually through thickening the composite structure with a low-density core material. This leads to a substantial increase of flexural rigidity of the structure, on the whole, without a significant increasing 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 thermoplastics, metallic and non-metallic materials, expandable and fireproof materials, balsa wood, etc. 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. However, there are constructive situations when these ribs can not be used. Another solution could be the increase of layers number that composes the structure but this leads to the disadvantage of the increase of resin and reinforcement consumption with economic and environmental consequences. A better and common solution is to use a thin nonwoven polyester mat as core.

II. THE STRUCTURE

To increase the stiffness of common fibre-reinforced composite laminates, and to avoid the previously presented disadvantages, the following structure is presented:

- 1 layer RT500 glass roving fabric;
- 2 layers RT800 glass roving fabric;
- 1 layer CSM450 chopped strand mat;
- 1 layer nonwoven polyester mat as core;
- 1 layer CSM450 chopped strand mat;
- A usually used gelcoat layer.

It can be noticed that this structure presents dissimilar skins. The core presents the most important influence in the overall structure's stiffness and flexural rigidity. The core material is a random oriented noncontinuous nonwoven polyester mat containing 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.

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 polyester, vinylester and epoxy resins and is suitable for hand lay-up and spray-up processes. Other processes like vacuum bag moulding can be used also. For instance, an application of this kind of structure is an underground large spherical cap shelter showed in Fig. 1 and formed by twelve curved shells bonded together. To withstand the soil weight, the wall structure present a variable thickness.This kind of structure can be used in outdoor applications also.

Manuscript received March 5, 2010. This work was supported by the Department of Automotives and Engines within Transilvania University of Brasov, Romania.

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Fig. 1. Large underground spherical cap shelter made from thin sandwich composite structures

III. STRUCTURE'S FLEXURAL RIGIDITY

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 (Fig. 2) 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 [1]:

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

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

If the skins present different materials and unequal thickness, like our structure with dissimilar skins (Fig. 3) and taking into consideration that the local flexural rigidities for the skins can not be neglected, which means that [1]:

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

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

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

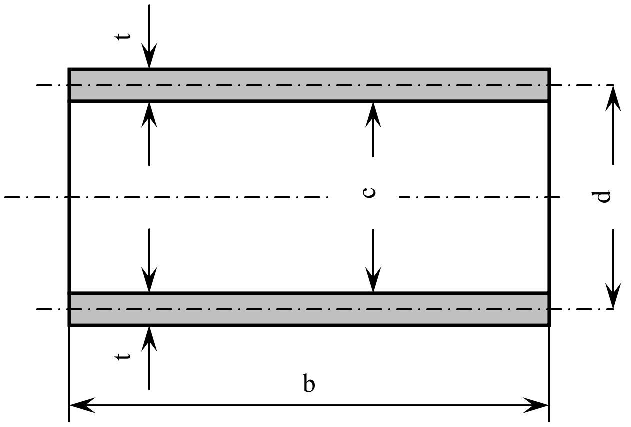

Fig. 2. Cross section of an open sandwich with equal skins

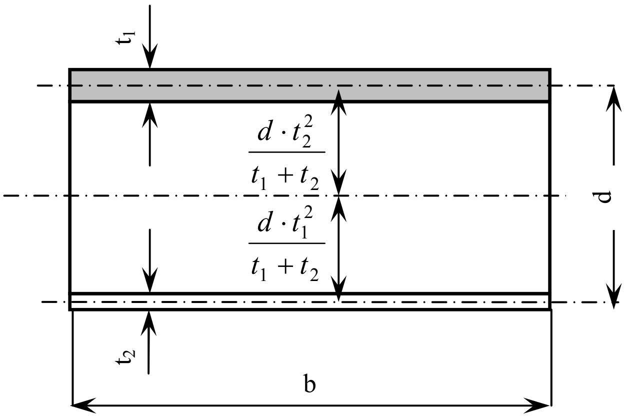

Fig. 3. Dimensions in a cross section of an open sandwich beam with dissimilar skins

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

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

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, because each skin is considered as a thin plate, the ratio between stress and strain is $\frac{E}{1 - \upsilon^2}$ [1].

IV. EXPERIMENTAL APPROACH

Tensile and three-point bend test have been used to determine the most important features of this structure. 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 subjected to bending

Features	Average dimensions
Width, b (mm)	15
Length (mm)	150
Sandwich thickness (mm)	8.27
Core thickness, c (mm)	4
Cross-section area (mm^2)	124.05
Upper skin's thickness, t_1 (mm)	3.1
Lower skin's thickness, t_2 (mm)	1.1
Distance, d (mm)	6.17

Table 2. Three-point bending test characteristics

Test features	Value
Test speed (mm/min)	4
Span (mm)	130

The tests have been carried out on a LR5K (5 kN maximum load) as well as on a Texture Analyser (1 kN maximum load) testing machines, produced by Lloyd Instruments. Stresses and strains have been measured applying strain gauges on a structure's curved shell.

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;
- Extension at maximum load;
- Maximum bending strain at maximum load;
- Load at maximum extension;
- Maximum bending stress at max. extension;
- Extension at maximum extension;
- Maximum bending strain at max. extension;
- Load at minimum load;
- Maximum bending stress at min. load;
- Extension at minimum load;
- Maximum bending strain at minimum load;
- Load at minimum extension;
- Maximum bending stress at minimum extension;
- Extension at minimum extension;
- Maximum bending strain at minimum extension;
- Load at break;
- Maximum bending stress at break;
- Extension at break;
- Maximum bending strain at break.

Regarding the thermal approach of this structure, the expansions of the upper skin as well as for the whole sandwich structure have been measured. Coefficients of thermal expansion and the alpha feature for the upper skin have been also determined. The coefficients of thermal expansion have been measured using a DIL 420 PC dilatometer from NETZSCH (Germany), on both glass fabric reinforced polyester skin and the whole structure. For each sample, two successive heating stages in order to size the influence of the thermal cycling, and temperature interval from 20^0C to 250^0C, at a heating rate of 1 K/min into a static air atmosphere have been used. To eliminate the systems errors, the dilatometer has been calibrated by measuring a standard SiO_2 specimen under identical conditions.

V. RESULTS

Regarding the tensile tests, the most important features of the sandwich composite structure (e.g., Young modulus, tensile strength and load at break) are presented statistically in form of maximum, minimum and mean values as well as the standard deviation (Figs. 4–6). The results for the load at break are more scattered than those for Young modulus and tensile strength showing that the standard deviation is quite high. In case of the three-point bend tests, the most important features of the sandwich composite structure (e.g., Young modulus of bending, stiffness, flexural rigidity and load at break) are presented in Figs. 7–10. The results'coefficients of variance between both tests are presented in Figs. 11–12.

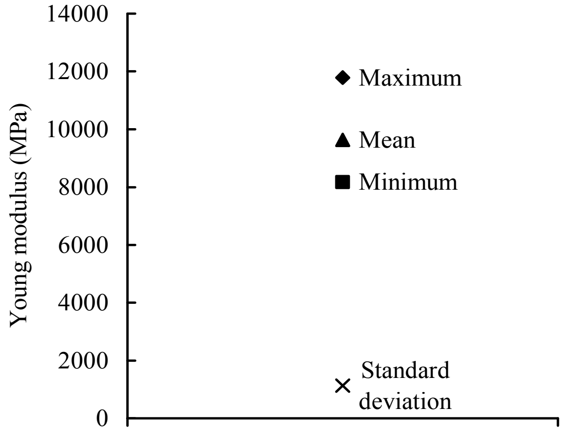

Fig. 4. Tensile test. Statistic results for the Young modulus

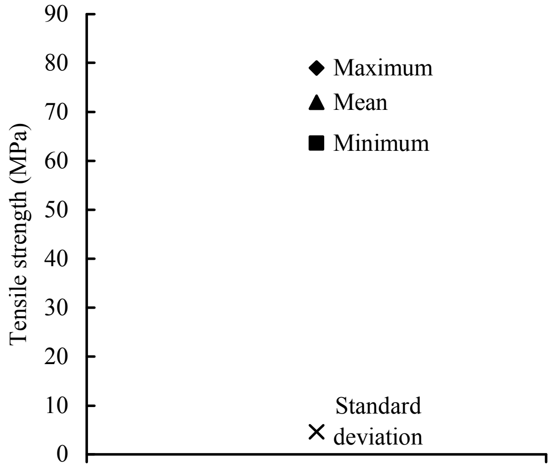

Fig. 5. Tensile test. Statistic results for the tensile strength

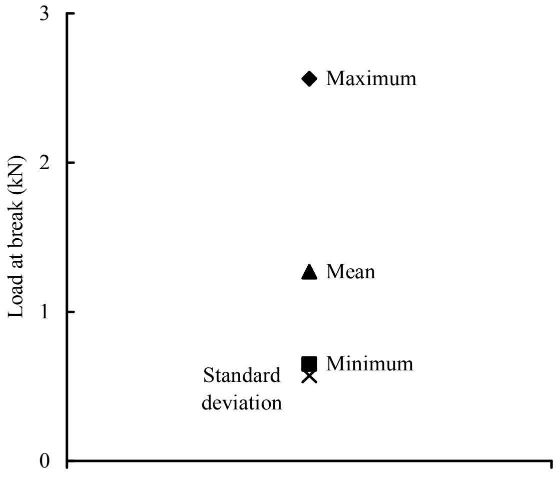

Fig. 6. Tensile test. Statistic results for the load at break

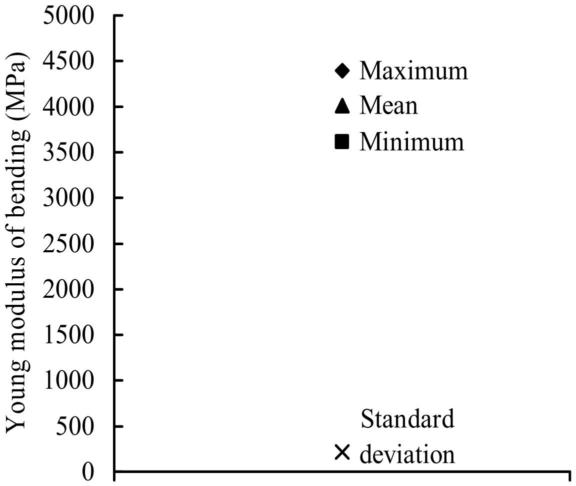

Fig. 7. Three-point bend test. Statistic results for the Young modulus of bending

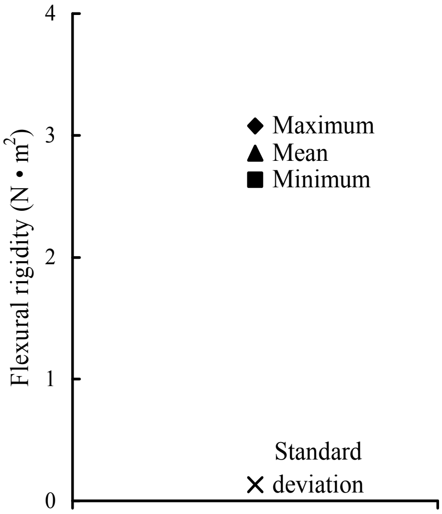

Fig. 8. Three-point bend test. Statistic results for the flexural rigidity •

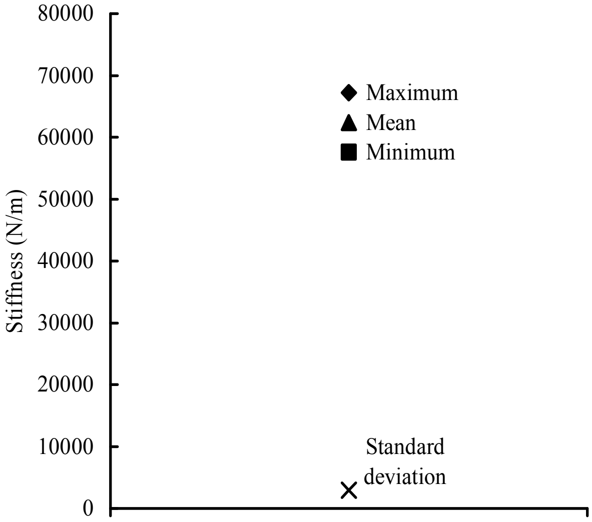

Fig. 9. Three-point bend test. Statistic results for stiffness

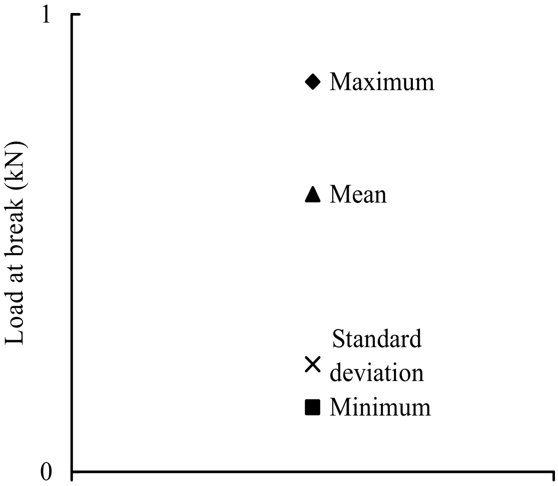

Fig. 10. Three-point bend test. Statistic results for the load at break

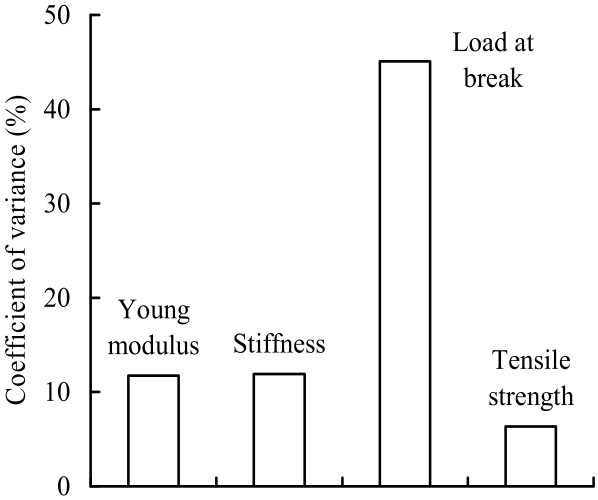

Fig. 11. Tensile tests. Coefficients of variance of the most important features of the sandwich structure

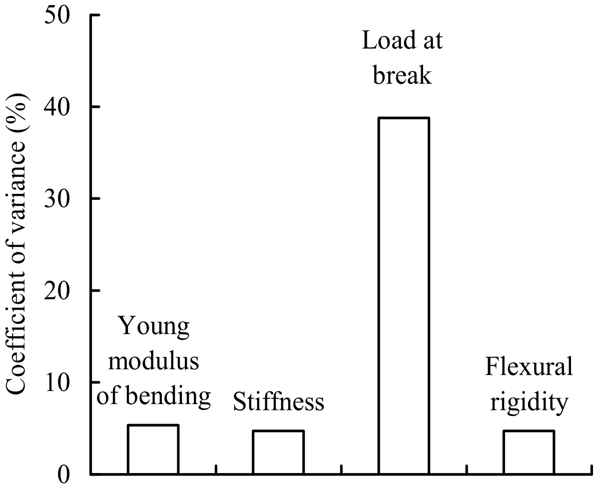

Fig. 12. Three-point bend tests. Coefficients of variance of the most important features of the sandwich structure

Curves of thermal expansion determined experimentally for two heating processes in case of the studied sandwich structure as well as for the upper skin are presented in Figs. 13 and 14. In Fig. 13, the negative thermal expansion in the first heating process is due to the beginning of curing in the upper skin structure. Regarding Fig. 14, in the second heating stage, the significant peak is due to the high shrinkage that took place in the sandwich structure.

In Fig. 15, following thermal features have been determined on the structure's upper skin in the first heating process:

- The thermal expansion (continuous line);
- The coefficient of thermal expansion (also known as technical alpha – dashed line);
- The alpha feature (doted line).

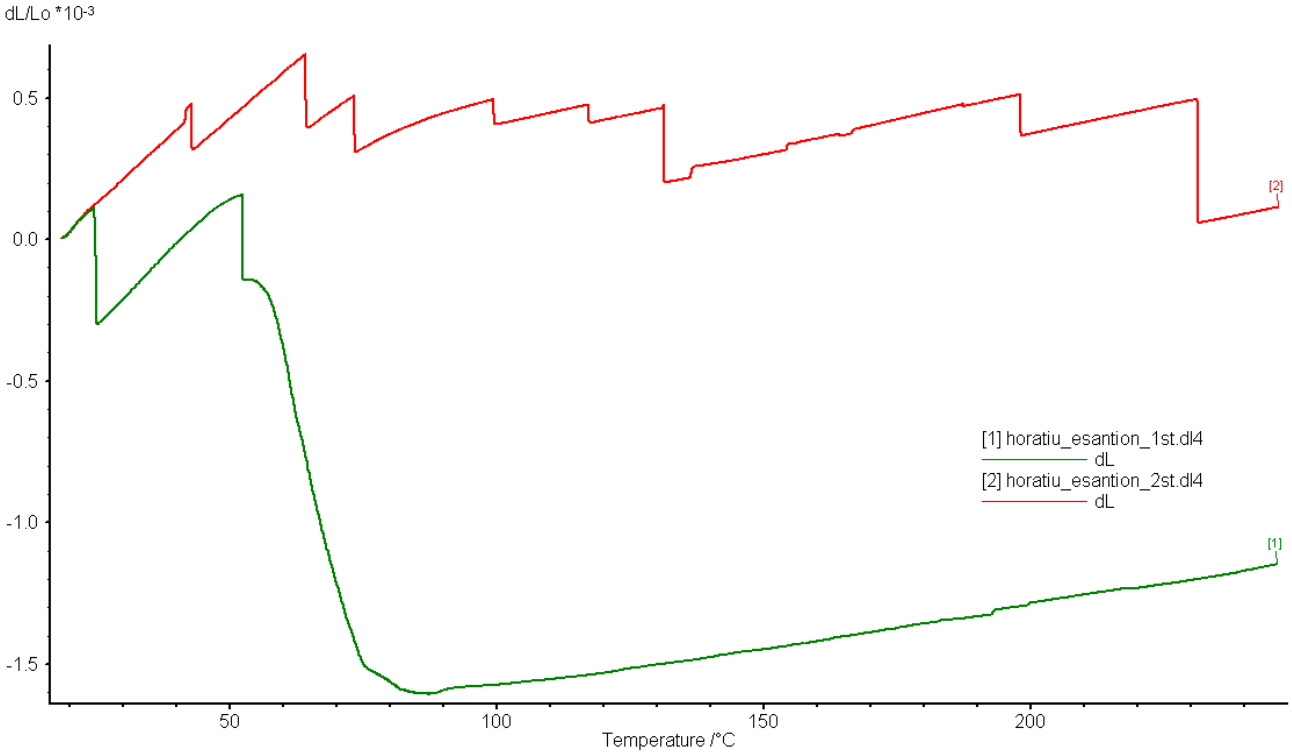

Fig. 13. Upper skin thermal expansions determined in two heating processes

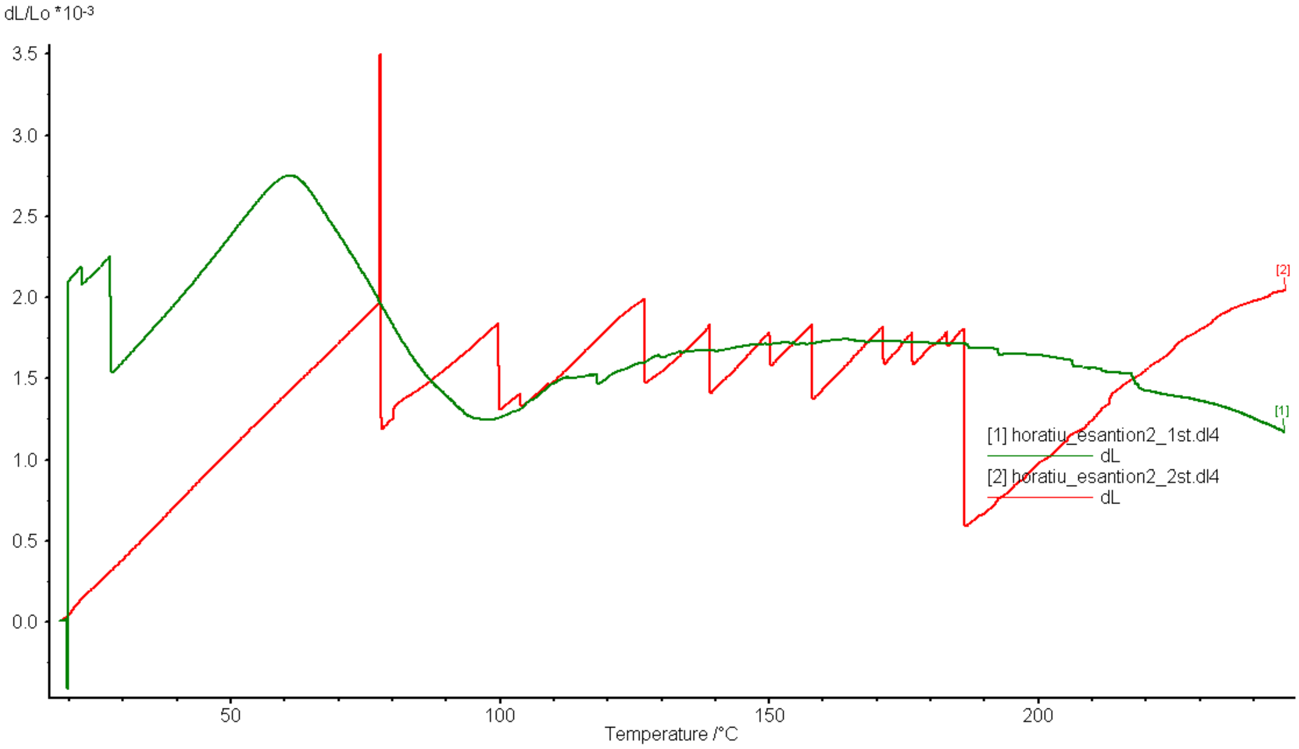

Fig. 14. Sandwich structure's thermal expansions determined in two heating processes

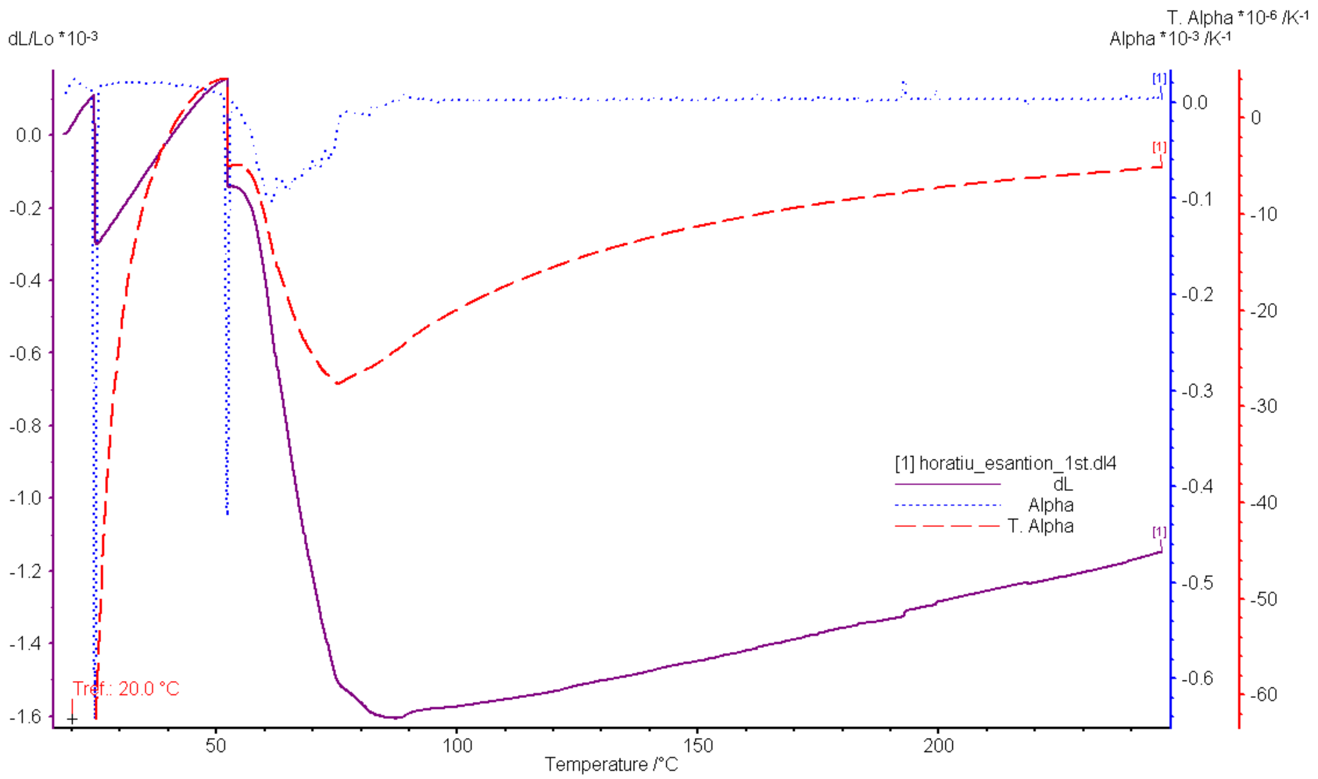

Fig. 15. Structure's upper skin thermal expansion, alpha feature and coefficient of thermal expansion determined in first heating process

VI. CONCLUSION

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 (Fig. 16). The 30% difference in structure's flexural rigidity determined theoretically and the experimental approach can be reduced by a better estimation of the upper and lower skin's Poisson ratios.

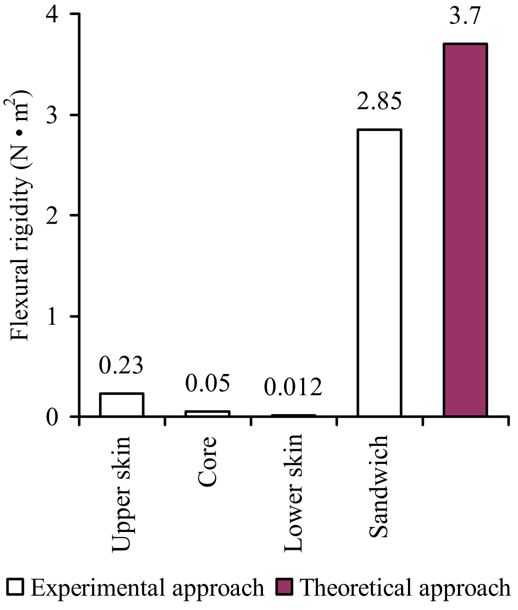

Fig. 16. Sandwich structure's flexural rigidity evaluation

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