STUDIU COMPARATIV ASUPRA COMPORTAMENTULUI STATIC ȘI LA OBOSEALĂ AL STRUCTURILOR SANDWICH CU DIFERITE TIPURI DE ÎNVELIȘURI DIN POLIMERI ARMAȚI CU FIBRE DE STICLĂ ȘI MIEZ DE FAGURE NOMEX

A COMPARATIVE STUDY ABOUT STATIC AND FATIGUE BEHAVIOUR ON SANDWICH STRUCTURES WITH DIFFERENT TYPES OF GLASS FIBER REINFORCED POLYMER SKINS AND NOMEX HONEYCOMB CORE

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The sandwich panels are frequently used as structural elements in various industrial applications, due to their increased rigidity reported to their weight, but also due to their advantages compared to conventional metallic structures or laminated composite structures. This paper presents the behaviour under static and fatigue regime of two sandwich structures with the same type of Nomex honeycomb core, but with skins made from glass fibre reinforced polymer composites, manufactured through different methods. Likewise, the mechanical characteristics of the two types of sandwich structures were compared and analysed. In this paper the behaviour under cyclical fatigue of the two sandwich structures, subjected to 3-point bending, was tested and predicted by implementing the accelerated testing techniques. The accelerated methodology developed in this paper has determined a significant reduction of the testing time for the analysed specimens. Consequently, the testing time for the GFRP1-Nomex specimens was reduced by 6.35 times, respectively by 7.9 times for the GFRP2-Nomex specimens, which determined a significant cost reduction in the testing of composite sandwich structures. Also, the main failure modes of the sandwich structures, subjected to Charpy impact, were identified and analysed using microscopically analysis.

Panourile sandwich sunt frecvent utilizate ca elemente structurale în diverse aplicații industriale, datorită rigidității lor ridicate în raport cu greutatea, dar și a avantajelor pe care le conferă în comparație cu structurile metalice convenționale sau cu structurile compozite laminate. Lucrarea prezintă comportamentul în regim static și la oboseală a două structuri sandwich cu același tip de miez fagure Nomex, dar cu învelișuri din compozite polimerice armate cu fibre de sticlă, fabricate prin metode diferite. De asemenea, au fost comparate și analizate caracteristicile mecanice pentru cele două tipuri de structuri sandwich. În cadrul acestei lucrări a fost descris și prezis comportamentul la oboseală ciclică a celor două structuri sandwich, supuse la încovoiere în 3 puncte, prin implementarea tehnicilor de testare accelerată. Această metodologie accelerată, dezvoltată în această lucrare, a determinat o reducere semnificativă a timpului de testare pentru specimenele analizate. Astfel, timpul de testare a fost redus de 6.35 ori pentru specimenele GFRP1-Nomex și respectiv cu 7.9 pentru specimenele GFRP2-Nomex, ceea ce determină o scădere semnificativă a costurilor privind testarea structurilor sandwich compozite. De asemenea, au fost identificate și analizate principalele moduri de defectare ale structurilor sandwich, supuse la impact Charpy, utilizând analiza microscopică.

Keywords: *glass fiber reinforced polymer, sandwich panels, bending, fatigue, accelerated testing*

1. Introduction

Sandwich structures with honeycomb core are used on a large scale in areas such as: aerospace (wings, elevators, ailerons, flaps, fairings, engine cowlings), automotive (inside panels), the renewable energy industry (wind turbine blades) constructions (insulating sandwich panels used to build facades, roofs, bulkheads or ceilings), marine industry (floors, consoles, hull, bulkheads), the railway industry (construction of high-speed trains, wagons), packaging industry (corrugated cardboard) [1]. Sandwich structures present: low weight, good corrosion resistance [2 - 4], thermal resistance and excellent energy absorption capabilities [5], high stiffness-to-weight ratio, good buckling resistance [6,7] and good fatigue resistance [8 - 10].

The process of manufacturing sandwich structures consists into providing a package of

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multiple planar layers of identical or different materials, assembled by gluing, thus conferring rigidity to the structure. The composite sandwich structures can act [11]: insulators or sound walls that take bending strain, but they are also used due to their high hardness while behaving like a beam which can take mechanical stress (compression, bending, shear, impact). Also recent studies have been conducted [12,13] on the damped dynamic response of sandwich composite structures with different cores (polystyrene, polypropylene honeycomb) and established a methodology to determine: damping factor per unit the mass and length, the power loss factor and the dynamic modulus of elasticity.

In this paper, the analyzed structure has glass fibre reinforced polymer (GFRP) skin and Nomex honeycomb core. As for the core material analyzed in this paper, phenolic resin-impregnated aramid paper was used [14], known as Nomex (E. I. du Pont de Nemours Corp., Wilmington, DE, USA). Nomex honeycomb core is found in various applications: boat hulls, auto racing bodies and military shelters, aerospace structures, railway and shipyard industry. Nomex honeycomb core is intensely scrutinized in various specialized studies about its behaviour in compression [15], in three-point bending [16], on tensile [15,17] and on fatigue [18].

For composite sandwich structures, characterization in static is not enough and need more information about their properties with regard to fatigue and mean lifetime in dynamic conditions. In this paper it was investigated the behaviour and performance in static and dynamic regime of some sandwich structures with two types of glass fibre skins and Nomex core. GFRP-Nomex sandwich structures were tested in static for: three-point bending, flatwise compression and Charpy impact test and the main mechanical characteristics were determined. For the dynamic regime it was proposed a new methodology that accelerates the testing regime of sandwich structures by increasing the loading frequency. Using this acceleration methodology it can be determined in a short time, the mean life of GFRP-Nomex sandwich specimens.

The novelty of this paper consists in the methodology of accelerated testing, proposed and validated for the dynamic tests, by which the testing regime of the sandwich structures is accelerated by intensifying the load frequency. By using this accelerated testing methodology, implemented for the first time on composite sandwich structures, the mean life time for the GFRP-Nomex sandwich specimens can be determined in a short period of time. Implementing the accelerated techniques implies using a higher level of stress, in order to identify one or more degradation factors, based on which a fast acquisition of experimental data can be realised. In the early stages of the life cycle this methodology leads to the identification of the main failure modes, to the determination of the mechanical performances and to a fast evaluation of the life time of composite sandwich structures.

2. Experimental part

2.1. Materials

The first GFRP1-Nomex sandwich structure has two skins of woven glass fibre and Nomex honeycomb core. The GFRP1-Nomex structure is made of two prepreg style 7781 fibreglass skins with the prepreg resin content of 44%. The GFRP1-Nomex core structure consists of hexagonal Nomex honeycombs with the cell size and density being 4.8 mm and 32 kg/m^3. This structure consisting of two skins of fibreglass prepreg and Nomex core assembly has been subjected to hot pressing, resulting in a final 8 mm thickness of the sandwich structure.

The second GFRP2-Nomex sandwich structure consists of two skins made of fibreglass fabric with a specific weight of 300 g/m^2 and a Nomex core with the hexagonal cell size and density being 4.8 mm and 32 kg/m^3. To manufacture this structure a wooden board is required, on which is laid a laminate foil to give the structure as a smooth surface as possible. Two layers of glass fiber fabric are placed with a brush and the epoxy resin uniformly applied. The Nomex core is positioned and then are added the two layers of fibreglass fabric by applying uniform layers of epoxy resin. Over the last layer of fibre lamination is put a delamination foil and a fabric with a minimum thickness of 20 mm. The textile material is used so that the vacuum bag does not stick to the structure and to remove all air from the resin. The structure formed is placed in a vacuum bag and impregnation of the composite is achieved, resulting in a 9 mm thick sandwich structure.

2.2. Methods

2.2.1. Three-point static bending test

For three-point static bending tests there were cut 10 specimens of GFRP1-Nomex and GFRP2-Nomex sandwich panels. Ten specimens (of the two GFRP1-Nomex and GFRP2-Nomex sandwich panels) were tested in static bending in three-point, in accordance with ASTM C393 standard. The three-point static bending tests were conducted on a WDW-150S universal testing machine and the crosshead speed was set to 3 mm/min. The sandwich specimens were placed on the supports (radius R = 6 mm) with a distance of 110 mm between each other.

The three-point static bending tests had as main objective to determine the mechanical performances (bending strength, bending elasticity

Table 1

Dimensions of specimens tested in three-point static bending
Dimensiunile specimenelor testate în regim static la încovoiere în trei puncte

Material	Length (mm)	Thickness (mm)	Width (mm)	Span length (mm)	Core thickness (mm)	Facing thickness (mm)
GFRP1-Nomex	160	8	16	110	7.5	0.25
GFRP2-Nomex	160	9	16	110	7.5	0.75

modulus and other aspects related to load – displacement relationship) of the manufactured sandwich structures. The main dimensional characteristics of the specimens (GFRP1-Nomex and GFRP2-Nomex) tested in static bending three-points were presented in Table 1.

The method of the three-point static bending tests of GFRP1-Nomex specimens was described in Figure 1, similarly being performed the tests for GFRP2-Nomex structure.

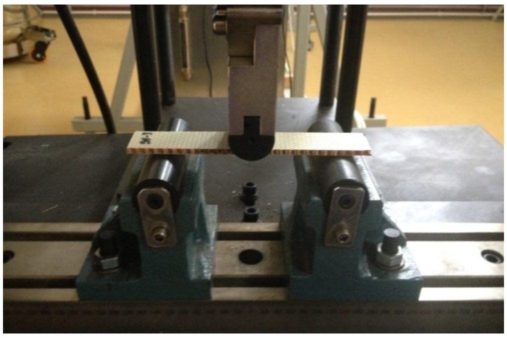

Fig.1 - Three-point-bending test setup/ *Schema de testare la încovoiere în trei puncte*.

2.2.2. Flatwise compressive test of GFRP-Nomex specimens

Five specimens of the two sandwich structures GFRP1-Nomex and GFRP2-Nomex were tested for compression using universal testing machine WDW-150S type (Figure 2). The specimen size and organization of flatwise compression test are consistent with MIL-STD-401B Sec.5.2.4 standard. These types of tests are used to determine the basic characteristics at the stress of compression (flatwise compressive strength and flatwise compressive modulus) of two kinds of sandwich panels (GFRP1-Nomex and GFRP2-Nomex). The dimensions of the test specimen sandwich to compression are 5 x 5 cm.

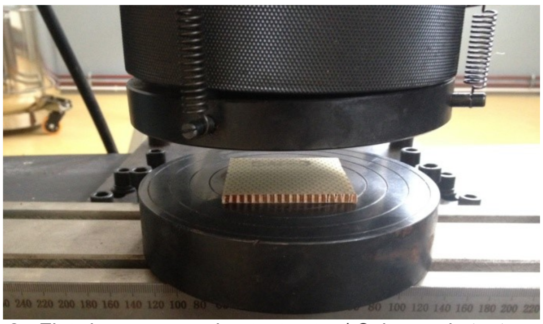

Fig. 2 - Flatwise compression test setup/ *Schema de testare la compresiune plană.*

2.2.3. Charpy impact test

For testing the GFRP-Nomex sandwich specimens at impact a Charpy hammer with the following characteristics was used: 66.55 N hammer's weight, arm length is 380 mm and the initial potential energy is 49 J. For impact analysis of specimens were tested ten specimens (of the two sandwich panels GFRP2-Nomex and GFRP1-Nomex) un-notched using a Charpy hammer. The impact test samples of the GFRP-Nomex sandwich are prepared according to the required dimension following the ISO 179-1 standard (Table 2).

Table 2

Dimensions of specimens tested on Charpy impact test/
Dimensiunile specimenelor sandwich testate la încercări de impact Charpy

Material	Length (mm)	Thickness (mm)	Width (mm)
GFRP1-Nomex	150	8	10
GFRP2-Nomex	150	9	10

For specimens without notch, the Charpy impact strength, a_{cU}, expressed in kJ/m^2 is determined by the relation (1):

$$a_{cU} = \frac{E_c}{d \cdot b} \cdot 10^3 \text{ [kJ/m}^2\text{]}, \qquad (1)$$

where: E_c is the energy in joules, absorbed by breaking the test specimen of GFRP-Nomex; d is the thickness, in millimetres, of the test specimen of GFRP-Nomex; b is the width, in millimetres, of the test specimen of GFRP-Nomex.

For an accurate characterization of the failure modes of the composite sandwich structures, the Nikon Eclipse MA 100 optical microscope was used. It is provided with a NIKON microscope (with a resolution up to 1000X) and adequate software packages for quantitative and qualitative analyses on both ferrous and non ferrous materials.

2.2.4. The fatigue three-point bending tests

The composite sandwich structures show high reliability and long span for fatigue testing under normal conditions. For this reason, is opted for accelerated testing techniques. Through techniques of accelerated testing in the process of testing a sandwich structure is subjected to test conditions that exceed normal operation with the purpose of discovering defects, failure mode and lifespan in a short time. Specific stress regimes of accelerated tests are more intense, compared to the use regime, aiming the intensification of composite sandwich structures' degradation and so resulting a shortening time and economic costs related to testing. For fatigue three-point bending tests were made by each 15 specimens of the two sandwich panels GFRP2-Nomex and GFRP1-Nomex. The methodology for testing these specimens was in accordance with MIL-STD-401B Sec.5.3 standard and had the following dimensions (Table 3).

Table 3

The dimensions of the specimens subjected to the fatigue three-point bending tests/ *Dimensiunile specimenelor supuse la teste de încovoiere la oboseală în trei puncte*

Material	Length (mm)	Thickness (mm)	Width (mm)
GFRP1-Nomex	180	8	20
GFRP2-Nomex	200	9	20

The accelerated fatigue tests were conducted at three loading regimes with frequencies: 2 Hz, 2.5 Hz and 3 Hz using universal testing machine WDW-150S. Data from accelerated fatigue tests of sandwich structures were extrapolated for the normal test (loading frequency) of 1.5 Hz. At the three accelerated regimes (2 Hz, 2.5 Hz and 3 Hz) were tested in three-point bending fatigue, five specimens of each sandwich structure (GFRP1-Nomex, and GFRP2-Nomex). Accelerated fatigue data were generated at maximum load level of the static ultimate load at a stress ratio of R = 0.1.

3. Results and discussions

3.1. Static three-point bending test of GFRP-Nomex specimens

The static regime tests for three-point bending were performed on ten samples taken from the two sandwich structures GFRP1-Nomex and GFRP2-Nomex, until the occurrence of breakage. By using the WDW-150S testing machine program, were determined the load – displacement curves and the mechanical properties of the sandwich structures analyzed. Load – displacement graphs were constructed by averaging the values of load and displacement for specimens GFRP1-Nomex (Figure 3) and GFRP2-Nomex (Figure 4). Analyzing the behaviour in static testing, for three-point bending, of the 20 specimens of sandwich was observed a linear increase between the applied force and displacement and then a fall at maximum force in the moment of specimen breakage. The maximum force at which appeared irreversible damage to the material of sandwich structure analyzed was about 100 N to 350 N for specimens GFRP1-Nomex respectively, for specimens GFRP2-Nomex.

Following the three-point bending tests were determined also the maximum deformations, so that maximum deformation value was 2 mm, for GFRP1-Nomex specimens and for specimens GFRP2-Nomex was 6 mm. Both sandwich structures (GFRP1-Nomex and GFRP2-Nomex) tested, the bonding between the GFRP skin and the Nomex honeycomb core showed no problems, but the breaking specimens occurred over the entire surface of the sandwich structure without a debonding or delamination of the skin.

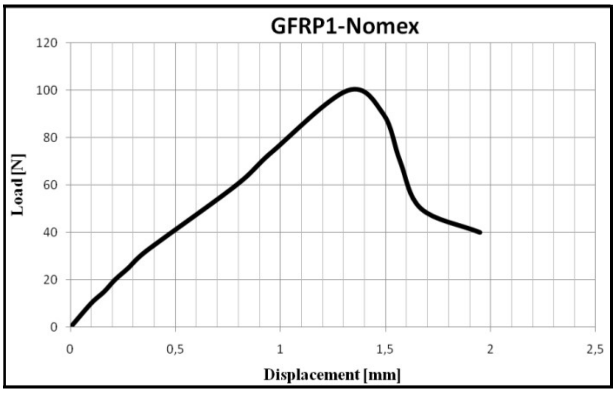

Fig. 3 - Load–displacement static bending behavior of the GFRP1-Nomex specimens/ *Comportamentul static la încovoiere și diagrama încărcare – deplasare pentru specimenele GFRP1-Nomex.*

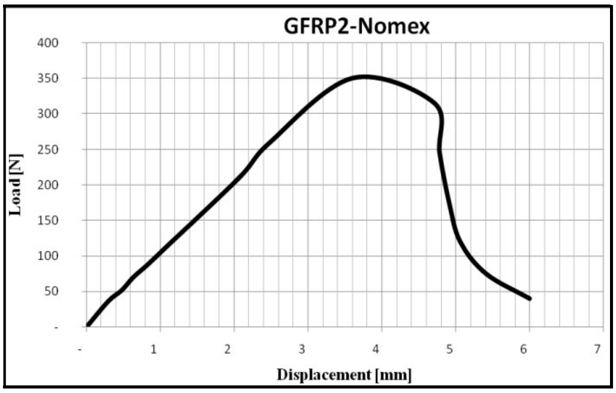

Fig. 4 - Load–displacement static bending behavior of the GFRP2-Nomex specimens/ *Comportamentul static la încovoiere și diagrama încărcare – deplasare pentru specimenele GFRP2-Nomex.*

The Load – Displacement curves for the two sets of specimens manifest themselves similarly, but nevertheless, in some phases of testing certain small differences in behaviour can be seen. These differences are: for the GFRP1-Nomex specimens the decrease is sudden at the moment of maximal force, whereas for the GFRP2-Nomex specimens the decrease is smoother, determining even a transitional level. This difference appears mainly because the degradation of the cover of the GFRP1-Nomex specimens appears much faster and (the cover of the GFRP1- Nomex specimens) presents a lower rigidity compared to the cover of the GFRP2-Nomex specimens. After this level the two

Table 4

Statistical indicators determined from tests at three-point static bending for GFRP-Nomex specimens/ Indicatorii statistici determinați în urma testelor la încovoiere statică în trei puncte ai specimenelor GFRP-Nomex

Material	Mean (μ)	Standard deviation (s)	Coefficient of variation (δ) %
GFRP1-Nomex -Bending Strength (MPa)	17	1.4	8.3
GFRP2-Nomex - Bending Strength (MPa)	61.3	5.4	8.9
GFRP1-Nomex - Bending Modulus (GPa)	1.704	0.1	7.7
GFRP2-Nomex - Bending Modulus (GPa)	6.105	0.5	9.7

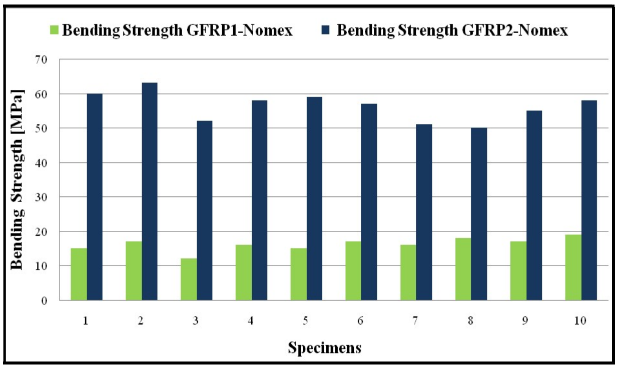

Fig. 5 - Bending strength of the sandwich specimens/ *Rezistența la încovoiere a specimenelor sandwich.*

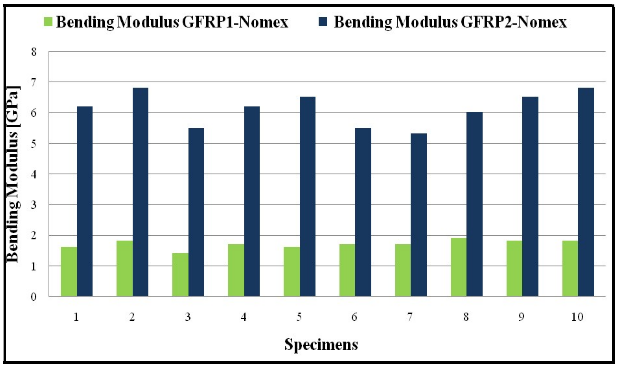

Fig. 6 - Bending modulus of the sandwich specimens/ *Modulul de elasticitate la încovoiere a specimenelor sandwich.*

structures present a similar zone of structural stabilization.

Based on the size of specimens and the test conditions were determined main mechanical characteristics of sandwich structures: bending strength and bending modulus. As can be seen in Figures 5 and 6, the bending strength and the modulus of elasticity of the GFRP1-Nomex sandwich specimen is about 3.5 times lower compared with those obtained for GFRP2-Nomex specimens. Analyzing the values of mechanical properties (bending strength, bending modulus, load - displacement) showed that specimens of GFRP2-Nomex show much better features compared with GFRP1-Nomex specimens, due primarily skin thickness which is 3 times higher, but also of how was manufactured.

The main statistical indicators were calculated for values of strength/modulus on three-point bending of specimens under static regime for GFRP1-Nomex and GFRP2-Nomex (Table 4). If the coefficient of variation (δ) is close to zero (δ < 30%), then the statistically computed data (coefficient of variation δ is in the range 7.3% to 9.7%) is homogenous and the calculated mean is representative for these sets of values.

From the static tests under 3-point bending, the mechanical characteristics of the sandwich structures were determined. The performances of the GFRP2-Nomex sandwich structures in the static tests under 3-point bending were superior compared with those of the GFRP1-Nomex structure, mainly because of the layer's thickness and the used production mode.

3.2. Flatwise Compressive Properties of the GFRP-Nomex sandwich

The main purpose of the flatwise compression tests of sandwich structures was to determine their ability to withstand a load applied in a short period of time and to determine the specific mechanical characteristics of these tests (flatwise compressive strength and flatwise compressive modulus). Further the values deter-

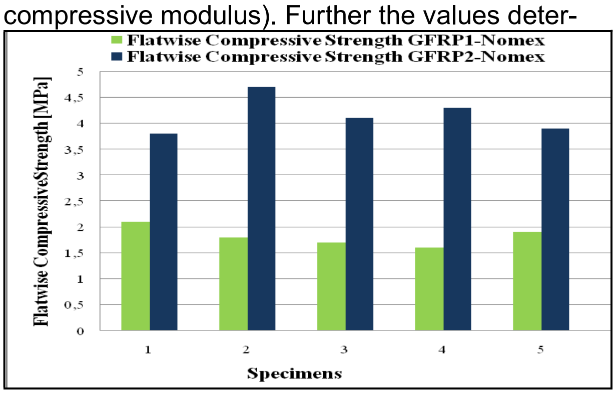

Fig. 7 - Flatwise compressive strength of the GFRP-Nomex specimens/ *Rezistența la compresiune plană a specimenelor GFRP-Nomex.*

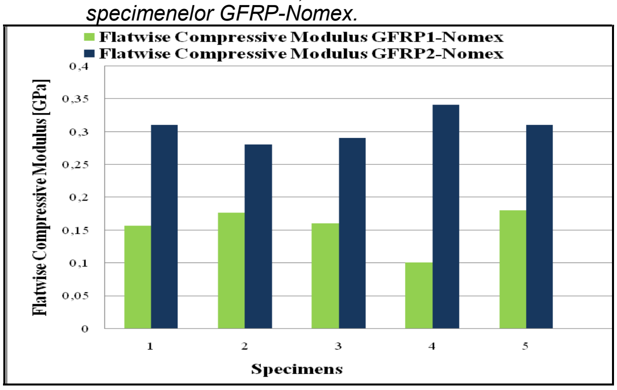

Fig. 8 - Flatwise compressive modulus of the GFRP-Nomex specimens/ *Modulul de elasticitate la compresiune plană a specimenelor GFRP-Nomex.*

Table 5

Statistical indicators determined for GFRP-Nomex specimens at flatwise compressive tests/ *Indicatorii statistici determinați în urma testelor la compresiune plană ai specimenelor GFRP-Nomex*

Material	Mean (µ)	Standard deviation (s)	Coefficient of variation (δ) %
GFRP1-Nomex –Flatwise Compressive Strength (MPa)	1.82	0.19	10.57
GFRP2-Nomex –Flatwise Compressive Strength (MPa)	4.16	0.36	8.6
GFRP1-Nomex –Flatwise Compressive Modulus (GPa)	0.15	0.03	20.77
GFRP2-Nomex –Flatwise Compressive Modulus (GPa)	0.31	0.02	7.52

Table 6

Statistical indicators determined from Charpy impact test on GFRP-Nomex specimens/ *Indicatorii statistici determinați în urma testelor la impact Charpy ai specimenelor GFRP-Nomex*

Material	Mean (µ)	Standard deviation (s)	Coefficient of variation (δ) %
GFRP1-Nomex -Impact Strength (kJ/m^2)	7.97	0.82	10.26
GFRP2-Nomex -Impact Strength (kJ/m^2)	53.83	3.72	6.92

mined for compressive strength were graphed (Figure 7) and for flatwise compressive modulus (Figure 8), for the 10 specimens tested in compression.

As can be seen from Figure 7, the compression strength is 2.3 times larger for GFRP2-Nomex structures as compared to GFRP1-Nomex structures. The differences in compression between the two structures are not as high as the three-point bending strength because the compressive behaviour is influenced primarily by the structure and characteristics of the Nomex core, which is the same for both.

Analyzing from the statistical point of view, the values determined from experimental tests for flatwise compressive strength and flatwise compressive modulus was found that the coefficient of variation presented values up to 30%, resulting in a homogeneous data determined experimentally and a good representativeness of the mean for these values (Table 5).

In the compression tests the thickness of the skin and the production mode were not as important, because a large part of the applied load was absorbed by the Nomex honeycomb core, that presents the same mechanical characteristics. As resulted from the compression tests, we can say that the two GFRP-Nomex sandwich structures provide/offer a high resistance to compression and shearing.

3.3. Charpy impact test

In order to determine the toughness of the sandwich structure of the impact tests were carried out using the Charpy pendulum. Results of this study include the Charpy impact strength, failure mechanism and microscopic examination of the GFRP-Nomex specimens. The impact tests are done by swinging the Charpy hammer at a height of 710 mm. After the Charpy hammer is dropped, it travels a trajectory of an arc and contacts the specimen sandwich. After breaking of the sandwich specimen, the Charpy hammer rises to a certain position. The difference between the potential energies of the hammer, the initial position and the end position, is the breaking energy of the sandwich specimen. The resistance values for Charpy impact test of specimens GFRP1-Nomex and GFRP2-Nomex determined from experimental tests have been described in Figure 9.

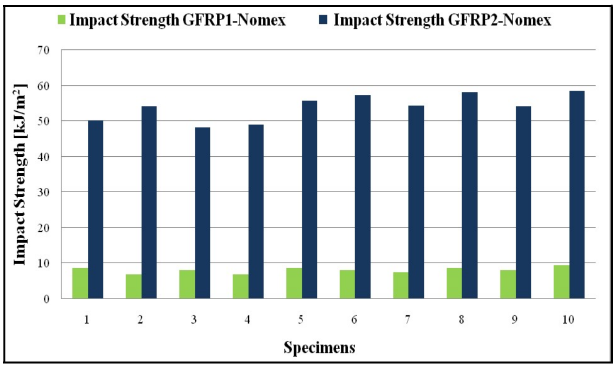

Fig. 9 - Charpy impact strengths of the GFRP-Nomex specimens/ *Rezistențele la impact Charpy ale specimenelor GFRP-Nomex.*

From the calculation of statistical indicators resulting from Charpy impact tests was able to ascertain that the structures of GFRP2-Nomex showed much higher values of impact strengths compared to GFRP1-Nomex. It has been concluded that the specimens' skin structure is a key factor in determining the impact performance. Charpy impact test values for GFRP1-Nomex structure are 6.75 times lower compared to the structure of GFRP2-Nomex. From the calculated values (Table 6) of the coefficient of variation was seen that the data of the impact tests are homogeneous and the calculated mean is representative of the entire data set.

In the case of Charpy impact tests, the majority of specimens showed a complete break without detachment or delamination of the GFRP skin from the Nomex core structure. A specimen of each structure (GFRP1-Nomex and GFRP2-Nomex) had an incomplete fracture of hinge type break. The two sandwich structures which have submitted incomplete break were analyzed using optical microscope Nikon Eclipse MA 100.

The GFRP1-Nomex structure showed a partial break (Figure 10. a, e) of the upper skin and a cracking of the Nomex core over the entire

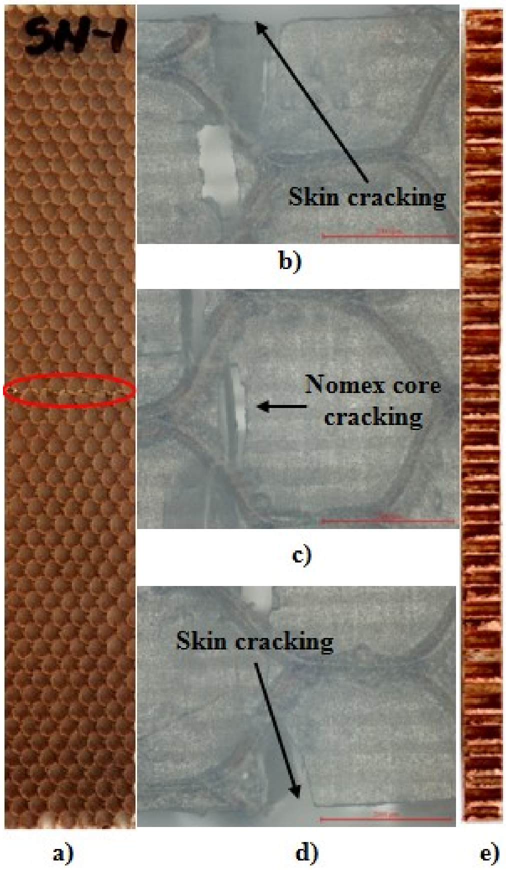

Fig. 10 – Failure mode of the GFRP1-Nomex specimen: a) top view; b), c), d) macroscopic views - 20X magnification; e) cross section view/ *Modurile de defectare ale specimenelor GFRP1-Nomex: a) vedere de sus; b), c), d) imagini macroscopice cu mărire 20X; e) secțiune transversală a specimenului.*

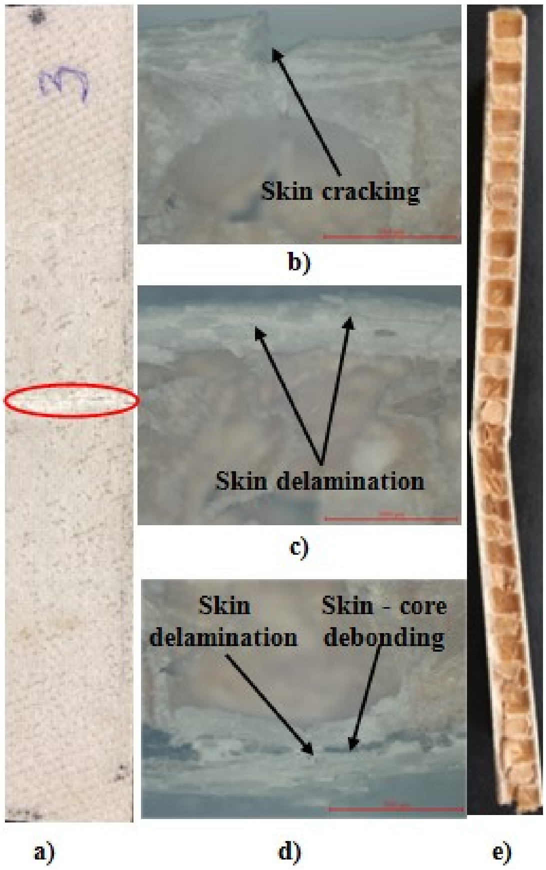

Fig. 11 – Failure mode of the GFRP2-Nomex specimen: a) top view; b), c), d) macroscopic views - 20X magnification; e) cross section view/ *Modurile de defectare ale specimenelor GFRP2-Nomex: a) vedere de sus; b), c), d) imagini macroscopice cu mărire 20X; e) secțiune transversală a specimenului.*

contact with Charpy hammer. Even if the specimen has not subjected to a complete break, it was observed destruction of the Nomex core and how the crack increased and propagated along the contact surface with the Charpy hammer (Figure 10. b, c, d). Also, it could be observed that the GFRP skin did not show debonding or delamination (Figure 10. b, d) in the immediate vicinity of the partial breaking.

The GFRP2-Nomex structure showed a partial break (Figure 11.a,b) of the skin and a cracking of the Nomex core to the end of the specimen (Figure 11. e). At a macroscopic analysis of the upper skin (the one which first contacts the Charpy hammer and is subjected to tension load) was able to establish that it was broken on a small part. From this minor crack, the structure's upper skin presented two areas of detachment layer where delamination occurred (Figure 11. c). From the area of the upper skin breakage the crack propagated through the whole Nomex core and reached the lower skin (Figure 11. d). The lower skin was debonded from the Nomex core and caused a delamination of the fibreglass layers.

Instead at the Charpy impact tests the performances of the specimens were significantly influenced by the thickness of the skin. Consequently, the behaviour under impact of the sandwich structures is different, determining different failure modes and quantitative values of the Charpy impact resistance. We can observe that the GFRP2-Nomex structure has constantly the highest rigidity and that the GFRP1-Nomex structure the lowest rigidity.

3.4. Accelerated bending fatigue tests

To determine the lifetime and failure mechanisms of sandwich composites structures requires very lengthy tests. In order to obtain such information as quickly as possible accelerated fatigue test methodologies are used. Degradation of composite sandwich structures is totally different from the degradation of a metallic structure sandwich panel. It can be said that the destruction due to fatigue can occur faster and more frequently in metal sandwich structure compared with sandwich composite structures. The durability of sandwich structures vary depending on the type

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Table 7

The calculation methodology for determining the number of cycles in normal regime of GFRP1-Nomex and GFRP2-Nomex specimens/ *Metodologia de calcul cu privire la determinarea numărului de cicluri în regim normal de utilizare a specimenelor GFRP1-Nomex și GFRP2-Nomex*

No.	Number of cycles in accelerated conditions GFRP1-Nomex	Number of cycles in accelerated conditions GFRP2-Nomex	Accelerated Frequency Level [Hz]	Acceleration factor GFRP1-Nomex	Acceleration factor GFRP2-Nomex	The number of cycles in normal conditions GFRP1-Nomex	The number of cycles in normal conditions GFRP2-Nomex
1	15307	38826				64850	197255
2	16404	40015				69497	203296
3	18854	41699	2.5	4.2366	5.0805	79877	211852
4	19578	43798				82944	222516
5	21776	46619				92330	236848
6	10363	20752				73503	188331
7	10573	21071				74992	191226
8	11053	22801	3	7.0928	9.0753	78397	206926
9	11759	24373				83404	221192
10	12236	24599				86788	223243
11	4366	10199				47876	151160
12	5105	11237				55979	166545
13	6892	13360	3.5	10.9656	14.8211	75575	198010
14	8012	14556				87856	215736
15	8431	16867				92451	249987

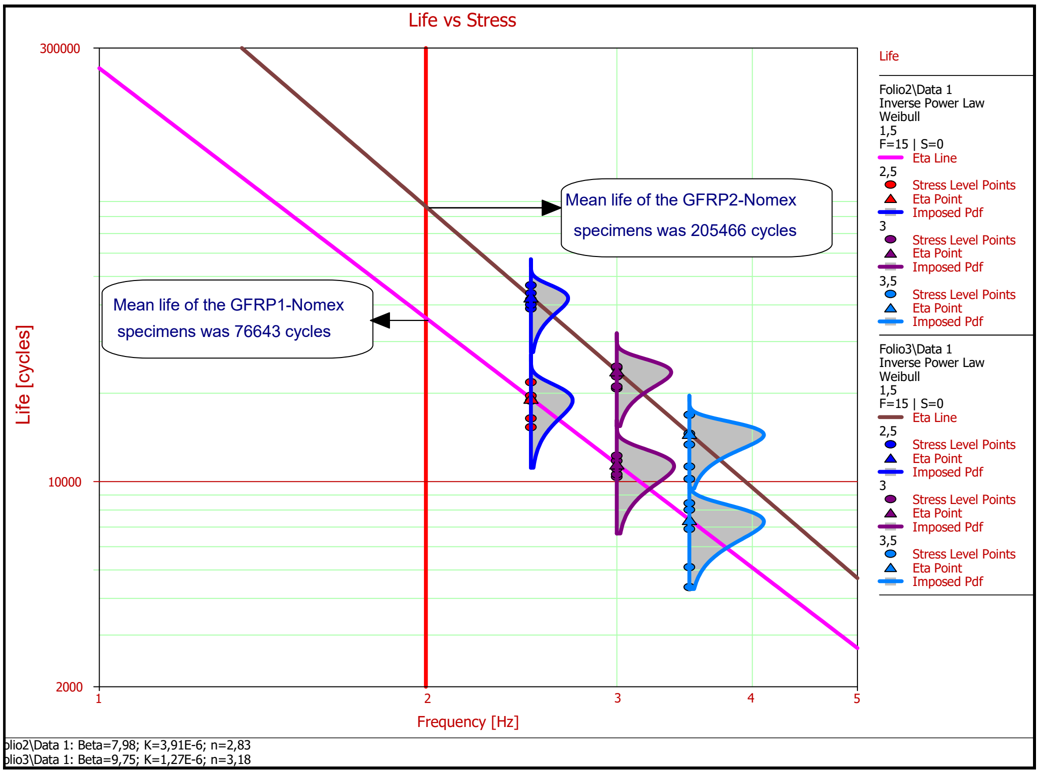

Fig. 12 – The graphical method for determining the mean number of cycles for the GFRP1-Nomex and GFRP2-Nomex specimens/ *Metoda grafică de determinare a numărului mediu de cicluri pentru specimenele GFRP1-Nomex și GFRP2-Nomex*

of fibre, the resin used the arrangement of laminate in the composite material used, the adhesive used and the type of core used. In the case of this paper there were performed accelerated fatigue tests for three-point bending done on two sandwich structures (GFRP1-Nomex and GFRP2-Nomex) with different ways of manufacturing fibreglass skin and Nomex honeycomb of the same type. During cyclic bending fatigue stresses of sandwich structures occur simultaneously: tension (the upper skin), compression (the lower skin) and Nomex honeycomb core shear.

The sandwich structures analyzed in this study were tested under accelerated regime at a loading frequency of 2.5 Hz, 3 Hz and 3.5 Hz. Data from the accelerated regime (number of cycles to failure) were extrapolated in normal testing at a frequency of 1.5 Hz. This loading regime of 1.5 Hz frequency was selected using data from expert studies [19 - 21]. In these studies, the loading regime for accelerated testing methodologies of composite structures was 1.5 - 2 Hz. To extrapolate data the ALTA 7 software was used and the Inverse Power Law acceleration model and Weibull distribution (it suits very well to studies where the main mode of failure is fatigue). Fatigue tests were performed on each 15 specimens of each sandwich structure (GFRP1-Nomex and GFRP2-Nomex). Fatigue test results using three-point bending of specimens GFRP1-Nomex and GFRP2-Nomex were described in Table 7. The acceleration factor was determined using the known relationship for Inverse Power Law – Weibull model. By multiplying factor of acceleration and number of cycles were determined under accelerated number of cycles in normal regime for specimens of GFRP1-Nomex and GFRP2-Nomex.

Through the methodology to accelerate the loading frequency proposed in this paper information was obtained on testing behaviour in normal regime (1.5 Hz) for the GFRP1-Nomex and GFRP2-Nomex specimens. The main purpose of accelerated tests was to determine mean life in normal regime, at a frequency of 1.5 Hz loading, of specimens GFRP1-Nomex and GFRP2-Nomex. The most common method for determining the lifetime, of the information resulting from the accelerated tests is the graphical method. Using this method were extrapolated number of cycles of the accelerated regime in normal regime and were determined the mean life (Figure 12) for the two types of specimens GFRP1-Nomex and GFRP2-Nomex.

From Figure 12 it was found that GFRP1-Nomex specimens experienced a lifetime of 2.68 times lower in comparison with GFRP2-Nomex specimens. It has also been observed during the fatigue tests a good behaviour of GFRP1-Nomex specimens. This advantage translates into the fact that this type of testing is influenced by the structure of the core, not only by the skin from which there were manufactured. By implementing accelerated fatigue tests the test period was shortened by 6.35 times for GFRP1-Nomex specimens and by 7.9 times respectively for GFRP2-Nomex specimens.

The breaking of the sandwich structures under cyclical mechanical stresses is due to the occurrence, increase and propagation of cracks, debondings and delaminations. The behaviour of the sandwich structures under fatigue depends not only on the nature of components and the form of stiffening material, but also on the used loading level.

4. Conclusions

A honeycomb sandwich structure has a high bending rigidity and consists of two thin skins united by a relatively thick honeycomb core. These types of structures are commonly used in various industrial applications, from manufacturing industry and to the construction industry. In this paper there were investigated two sandwich structures with Nomex honeycomb of the same type but with different skins of GFRP structure and method of manufacture. It was studied the behaviour at static three-point bending, compression, and Charpy impact and were determined the mechanical characteristics specific to these types of tests. For impact tests, was carried out a macroscopic fracture analysis and were examined specimens and failure modes encountered.

An accelerated test methodology has been implemented for fatigue testing of specimens with fibreglass skin and Nomex honeycomb core. By the methodology proposed in this paper were determined the performances of sandwich structures (GFRP1-Nomex and GFRP2-Nomex) under accelerated stress conditions (increased loading frequency), which are more severe than for normal use, which leads to specimens' failure in a short time. The objective of these accelerated fatigue tests, to shorten the lifespan of the specimens by accelerating the mechanisms of failure, has been validated. The reduction of test duration of 6.35 times for GFRP1-Nomex specimens and of 7.9 times respectively for GFRP2-Nomex specimens was performed by the accelerated test technique proposed.

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