METODĂ DE ÎNCERCARE LA OBOSEALĂ A MATERIALELOR COMPOZITE CU MATRICE DE POLIESTER ŞI ARMATE DISPERS CU FIBRE DE STICLĂ
METHOD FOR TESTING GLASS FIBRE REINFORCED POLYMER COMPOSITES (GFRP'S) WITH POLYESTER MATRIX

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This paper presents a method, tested experimentally by designing a stand for fatigue testing of glass fibre reinforced polymer composites (GFRPs) with polyester matrix used in construction. The test is carried out by applying a repeated stress (0 to max) cycle load. Through operating parameters of the stand the method allows the testing of joints (adhesive or mechanical) between parts of composites. The stand is designed for simultaneous testing of six samples and is characterized by high energy efficiency with a power of only 5.5 kW as opposed to 65 kW as required by a classical tensile testing machine with hydraulic drive.

În această lucrare este prezentată o metodă, verificată experimental, prin realizarea unui stand pentru încercarea la oboseală a materialelor compozite cu matrice din poliester armate dispers cu fibre de sticlă utilizate în domeniul construcţiilor. Încercarea efectuată este tracţiune prin ciclu pulsant nul. Metoda permite, prin parametrii funcţionali ai standului, extinderea încercărilor şi asupra îmbinărilor (adezive sau mecanice) între piese din material compozit. Standul este conceput pentru încercarea simultană a şase epruvete simultan şi se caracterizează printr-o eficienţă energetică superioară având o putere instalată de 5,5 kW faţă de 65 kW cât ar necesita o maşină de încercat la tracţiune clasică cu acţionare hidraulică.

Keywords: *composites, fatigue testing, joints testing, repeated stress cycle load*

1. Introduction

Lately, in construction industry, glass fibre reinforced polymer composites (GFRPs) with polyester matrix are used more frequently. Thus in civil engineering are used these materials for structures, concrete reinforcing [1-4], roof elements, ornamental tiles, cladding, partitions, covering tiles for concrete floors exposed to heavy traffic, window sills, steps and risers, etc. In plumbing or public health engineering are used for plumbing hardware (water closets, bathtubs, lavatories etc.), swimming pools, pots and woven fibre containers. In urban development field the composites are used for lighting poles, manholes, urban furniture, stalls, kiosks etc. [5,6].

Some of these construction elements are subjected to varying loads in time for extended periods of time. These loads diminish the material strength during the service life of these elements. Problems are increasing if these construction elements are subjected to chemical corrosion during service life.

Consequently, experimental testing is needed in order to assess the behaviour of these materials in these conditions and results to be made available to designers and institutions dealing with quality control of these construction elements [7].

Getting this experimental data is time consuming. For example, testing a specimen to variable stress with the frequency of 7.5 Hz and a total of one million cycles means a five-day duration of the testing for eight hours per day of continuous operation of the testing machine.

To eliminate this drawback, the authors of this work have devised an original method and designed an experimental stand for studying the behaviour over time of composites used in construction subjected to long-term dynamic loads.

Given that fatigue testing of materials EN ISO 527-4 [8] recommends that each determination in certain stress conditions, to be the average of at least five attempts, the designed stand is comprised of six workstations, which means that six specimens can be tested simultaneously. This leads to two main advantages: achieving the same strict test conditions for test specimens in the same batch and reducing the time required to test by six times compared to testing stand with only one available workstation.

2. Working principle

Testing specimens for tension and compression by applying a repeated stress cycle load using the stand presented in this paper is done by imposing specimens' elongation, resulting in the test section of the specimen a state of tension (stress) corresponding to the achieved deformation.

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The installation on the test stand of identical specimens is done in pairs, as in Figure 1. One end of each specimen is articulated to the chassis by means of the gripper at the point *C* and C_1, and the other ends are hinged together in the point *B* at the end of a crank *AB*, of adjustable length *l*. In the initial position one specimen is not loaded and the other is at its maximum elongation, which means that the point *B* is on the direction of CC_1. By turning the crank AB about point A the two specimens deforms respectively the initial one which is not loaded lengthens and the other one shortens for half a turn, for the other half, deformations change their direction. In this way the specimen that lengthens produces a resistant force in the form of spring force, $F_1 = k \cdot \Delta l_1$ and the one that shortens produces a driving force still of elastic nature $F_2 = k \cdot \Delta l_2$ which, due to the chosen mounting scheme compensates the first resistant force.

Torque needed to perform the test is the sum of the torques in order to load each specimen, respectively:

$$M_t = M_1 + M_2 . \quad (1)$$

Variation of these torques for a complete rotation of the crank AB is shown in figure 2. It is noted that the resultant torque has a constant amplitude sine wave variation with respect to the horizontal axis and twice the frequency relative to the crank. This variation of the resulting torque requires the use of a flywheel in the driving kinematic chain accumulating kinetic energy during acceleration ($M_t > 0$) and gives in the braking phase ($M_t < 0$) considerably reducing unevenness of movement. Basically, during operation, the forces required to load the specimens compensate and the engine must supply power only to overcome friction forces in the drive kinematic chain and friction in the specimens' material, making this test bed very energy efficient.

The maximum elongation of a specimen is twice the length of the crank AB. Consequently, implementation of various levels of stress for determining the resistance to fatigue of the material requires that the crank length AB to be adjustable.

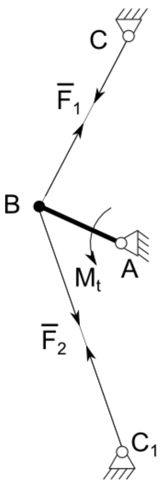


Fig. 1 - Working principle
Principiul de funcționare

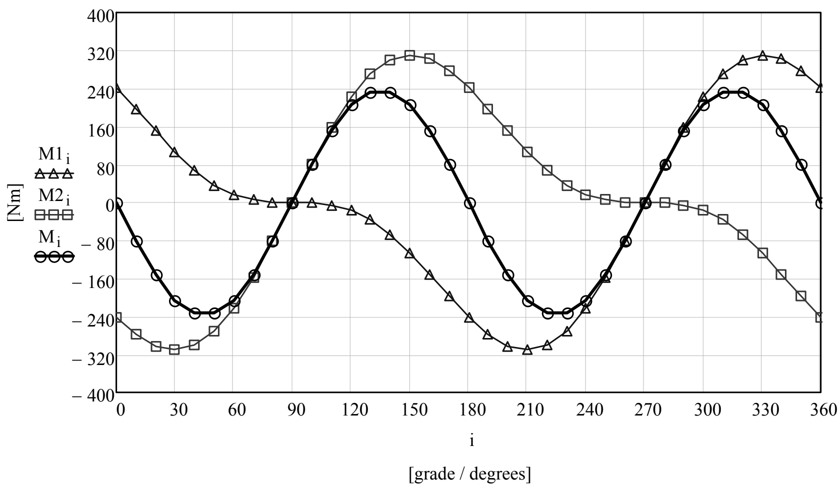


Fig. 2 - Torques variation / *Variația momentelor de răsucire.*

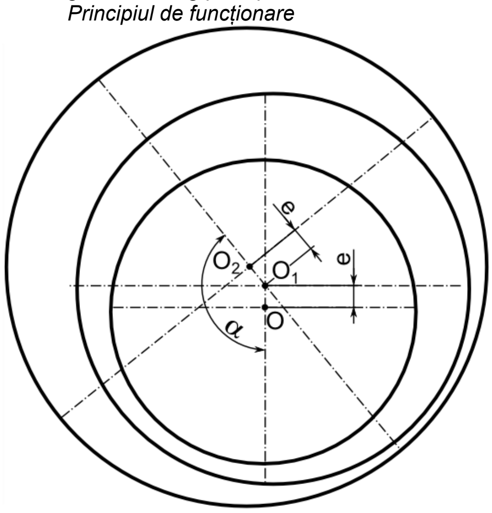


Fig. 3 - Elongation adjustment / *Reglarea alungirii.*

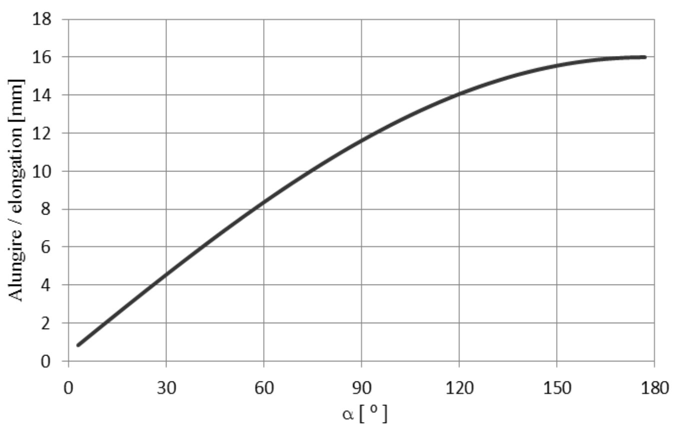


Fig. 4 - Adjusting curve / *Caracteristica de reglaj.*

This is solved practically, Figure 3, by making the crank in the form of two eccentric axes passing through O_1 and O_2, is equal to the eccentricity and mounted on a shaft with the axis passing through the point O. The first eccentric is integral with shaft and the second can rotate in respect to the first. The resulting eccentricity depends on the angle α between the two eccentrics and is calculated with the equation,

$$OO_2 = AB = 2 \cdot e \cdot \sin(\alpha / 2) \quad (2)$$

which is the adjusting curve of the testing stand, Figure 4.

3. Utilized specimens

The stand shown may be used for two types of tests, respectively material testing and joints testing being adhesive or mechanical, using appropriate specimens built in accordance with EN ISO 527-4 and ASTM D3039/D3039m-08 [9], Figure 5, as follows:

a) specimens to determine the fatigue strength of the composite material having the following dimensions: length 240 mm, width 20 mm, thickness 5 mm or 10 mm;

b) specimens to determine the fatigue strength of the joint between the parts assembled with glue, having the following dimensions: length 466 mm, width 20 mm, thickness 5 mm;

c) specimens to determine the fatigue strength of the joint between the parts assembled with screw and glue having the following dimensions: length 466 mm, width 20 mm, thickness 5 mm;

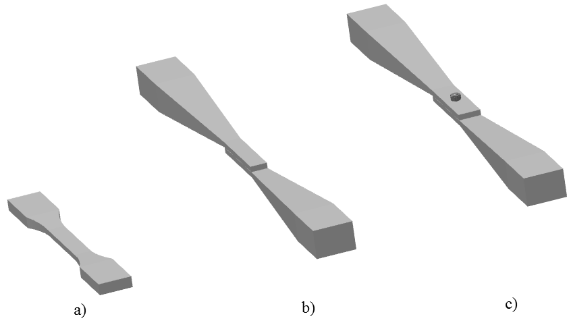
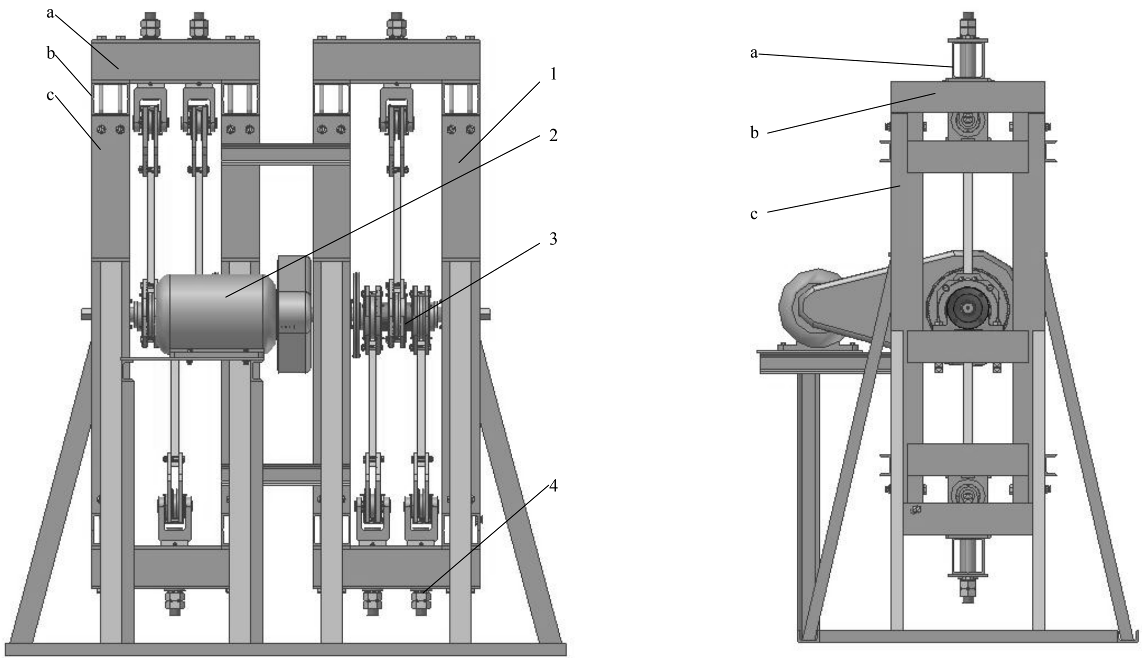


Fig. 5 - Specimens / *Epruvete.*

4. Stand description

The stand for fatigue testing of composites used in construction [10] consists of two parts: the mechanical system, Figure 6, and command and control system. Loading mechanism, Figure 7, is eccentric with adjustable eccentricity. The mechanism consists of eccentric shaft (1) on which is mounted an eccentric sleeve (2), discs (3) and (4) are fixed to the shaft (1) and (2) respectively on the eccentric bushing. The discs are provided with holes for dividing the movement (120 holes, 3 degrees), their attachment being made with bolt (5). The relative rotation of the two discs, and with them the two cam sleeve and shaft eccentrics (each equal to 4 mm) giving a result that the eccentricity can be quasi-continuously vary from 0 to 8 mm, yielding a complete revolution of the shaft an elongation of the specimen between 0 and 16 mm. The lifting and gripping devices are used to lock specimens being tested into position and taking over the gaps in the kinematic chain.



a b

Fig. 6 - The stand: a) frontal view, b) side view / *Standul: a) vedere frontală, b) vedere laterală.*

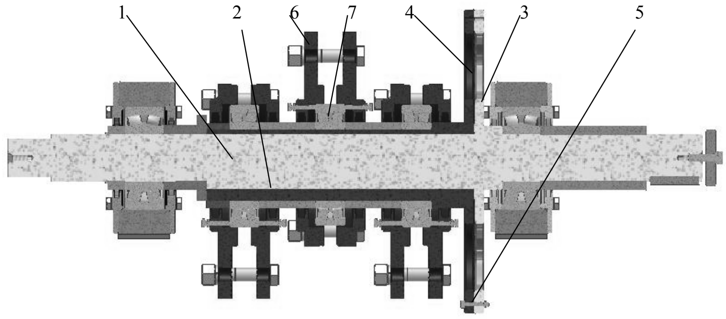


Fig. 7 - Loading mechanism / *Mecanismul de încărcare.*

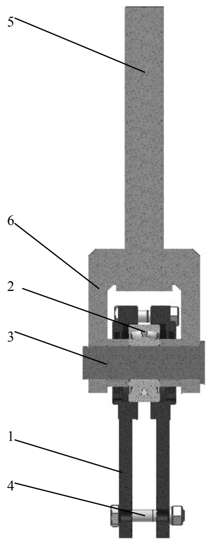


Fig. 8 - Device for taking over gaps / *Dispozitiv preluare jocuri.*

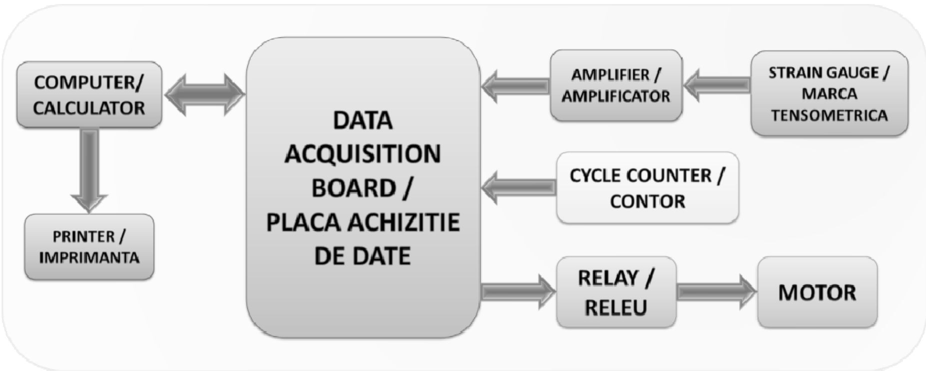


Fig. 9 - Command and control system / *Sistemul de comandă şi control.*

Gripping the specimens is done using wedge grips (6). They are fitted to the eccentric sleeve by means of spherical ball bearings (7). On the opposite side test specimens are fastened between the wedge-grips (1) fitted by means of a spherical bearing (2) on the fork's bolt (3). Tightening the wedge-grips is done using the screws (4). Mounting of wedge grips on spherical bearings is done to ensure axial loading of the specimens (compression and tension). The load adjustment of test specimens in order to achieve different types of cycles is done using screws (5) on forks (6).

Measuring forces that the specimens are facing during the test is done using strain gauges glued on the sides of the wedge grips (1), Figure 8. These wedge grips are longer than ones mounted on the eccentric bushing so that their shape does not adversely influence the accuracy of measurements. Measuring circuit is half bridge, with the active strain gauge grid arranged at 45° and glued on the surface of the wedge grip. The compensating strain gauge, which is identical to the active one, was placed on an unstrained part of the stand.

The block diagram of command and control system is shown in Figure 9 and contains the drive and control of three-phase electric motor, the computer and data acquisition board.

Data acquisition board and computer are needed to control the loading of test specimens and for cycles counting. Monitoring of test specimens load curve is done using data acquisition board. Cycle counting is done using a

Table 1

Semi-finished product with 5 mm thickness / *Semifabricat cu grosime de 5 mm*

Direction / *Direcţie* — Fibre glass symbol / *Simbol fibre sticlă*	*0°*	*-45°*	*90°*	*+45°*
	Fibre glass weight by directions [g/m^2] *Greutatea fibrelor de sticlă pe direcţii [g/m^2]*			
1. ELT 850	425	-	425	-
2. EBX 936	-	468	-	468
3. EOA 863	240	200	200	200
4. EBX 936	-	468	-	-
5. ELT 850	425	-	425	425
Total (g/m^2)	*1090*	*1136*	*1136*	*1050*

Table 2

Semi-finished product with 10 mm thickness / *Semifabricat cu grosime de 10 mm*

Direction / *Direcție* — Fibre glass symbol / *Simbol fibre sticlă*	0^o	-45^o	90^o	$+45^o$
	Fibre glass weight by directions [g/m^2] *Greutatea fibrelor de sticlă pe direcții [g/m^2]*			
1. EQX 1168	283	301	283	301
2. EQX 1168	283	301	283	301
3. EBX 446	-	223	-	223
4. EOA 863	240	200	240	200
5. EOA 863	240	200	240	200
6. EOA 863	240	200	240	200
7. EOA 863	240	200	240	200
8. EBX 446	-	223	-	223
9. EQX 1168	283	301	283	301
10. EQX 1168	283	301	283	301
Total (g/m^2)	*1125*	*1046*	*1125*	*1046*

Table 3

Experimental results / *Rezultate experimentale*

Batch no. Nr. lot	Thickness / Gros. 5 mm		Thickness / Gros. 5 mm, 3.5%NaOH		Thickness / Gros.10 mm		Thickness / Gros.10 mm, 3.5%NaOH	
	Cycles Nr. Cicluri	σmax. [MPa]	Cycles Nr. Cicluri	σmax. [MPa]	Cycles Nr. Cicluri	σmax. [MPa]	Cycles Nr. Cicluri	σmax. [MPa]
1	14000	132.0	5000	103.3	5100	104.7	5200	105.0
2	40300	119.0	19200	99.0	36000	101.8	33020	102.8
3	57520	109.6	50500	95.0	145256	88.0	200310	76.0
4	170790	98.0	185241	74.9	203025	75.0	261300	71.3
5	206321	89.0	251123	73.2	239776	67.0	402315	58.7
6	239052	86.0	535000	69.0	487000	59.8	556897	57.3
7	450000	75.3	700203	63.8	530022	580.	750036	55.0
8	854028	69.4	845754	61.5	789541	55.1	1007760	52.7
9	1027600	66.0	1035230	58.0	1100000	53.4	1083897	46.5

proximity sensor mounted in front of a protrusion made at the end of the eccentric shaft. The signal is fed into the computer and counted with the data acquisition board.

5. Technical features of the stand

- Maximum traction force of the specimen – 9000 daN.
  Maximum elongation of the specimen – 16 mm.
- Maximum distance between wedge-grips in the longitudinal direction of the specimen – 470 mm.
- Cycle frequency
  - constant – 7.5 Hz;
  - variable in 6 steps between 5 and 10 Hz;
- Fatigue testing by applying a repeated stress (0 to max or tension-tension) cycle load.
- Total power – 5.5 kW.

6. Composites under testing

The composites were made by laying alternate layers of the glass fibre in the matrix of polyester resin according to the tables 1 and 2. [11,12].

7. Tests performed and achieved results

7.1. Tests to determine the fatigue strength of the composite material

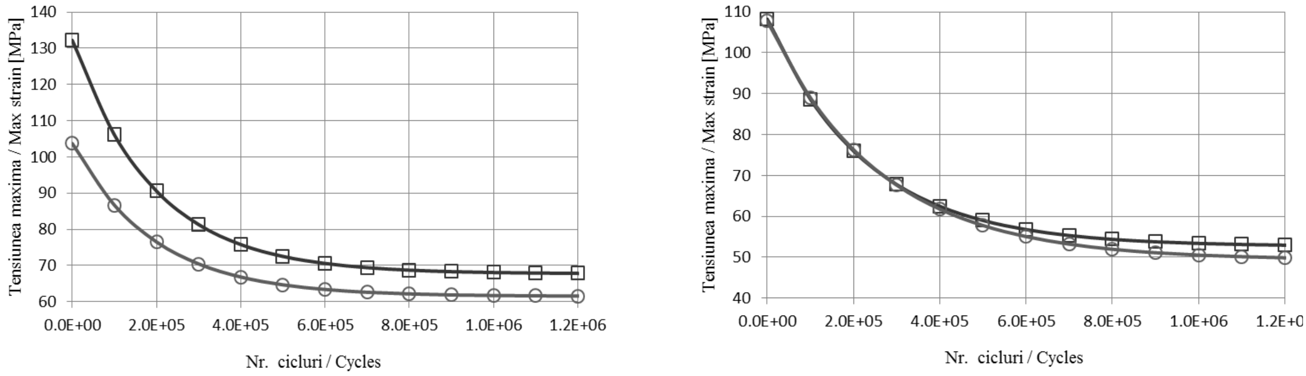
Batches of six specimens were used, §3, Figure 5 a, having two thicknesses of 5 mm and 10 mm, half of them were not subjected to chemical corrosion and the other half were subjected to chemical corrosion by keeping them for 30 days in a solution of NaOH 3.5%.

The samples were delivered by the beneficiary of experimental data; it does not specify the type of polyester resin used as matrix for composite or the adhesive used for bonding. The tests revealed the following results [11,12] in Table 3.

After analysing the results it shows that the maximum stress σ_{max} has an exponential distribution with negative power. This allows expressing the maximum stress as a function of n cycles by an expression in the form of:

$$\sigma_{\max}(n) = a \cdot e^{b \cdot n} + c \,, \qquad (3)$$

having the coefficients *a*, *b* and *c* determined from the experimental values. Equation 3 allows drawing the S-N curves (Wöhler curves) for that specific composite material, Figure 10.



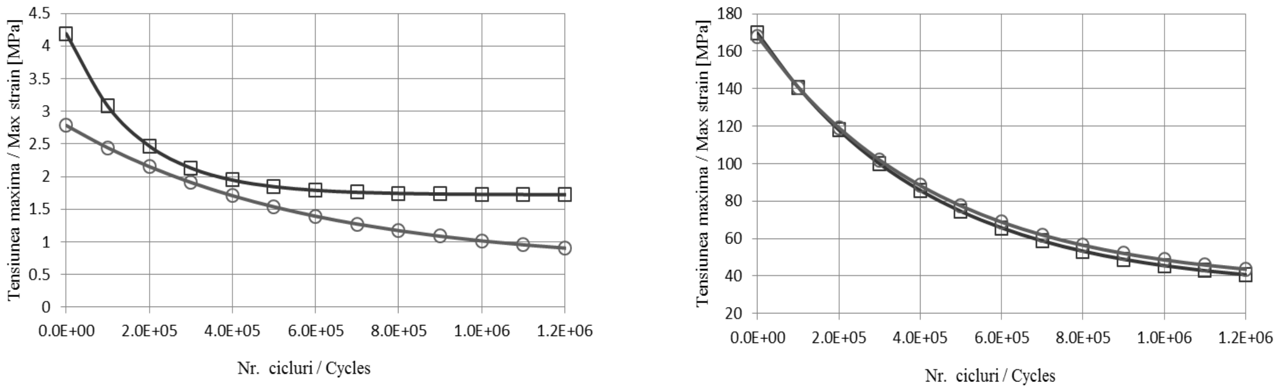
a b

Fig. 10 - S-N curves (square-no chemical corrosion, circle-specimens subjected to chemical corrosion); a) specimens with 5 mm thickness, b) specimens with 10 mm thickness */ Diagrame de rezistență la oboseală (patrat-fără coroziune, cerc-epruvete supuse la coroziune chimică); a) epruvete cu 5 mm grosime, b) epruvete cu 10 mm grosime.*

Table 4

Experimental results / *Rezultate experimentale*

Nr. lot / Batch nr.	Bonded joint		Bonded joint, 3,5%NaOH		Bonded joint and screw and nut		Bonded joint and screw and nut, 3,5%NaOH	
	Nr. Cicluri / Cycles	$\sigma_{max.}$ [MPa]	Nr. Cicluri / Cycles	$\sigma_{max.}$ [MPa]	Nr. Cicluri / Cycles	$\sigma_{max.}$ [MPa]	Nr. Cicluri / Cycles	$\sigma_{max.}$ [MPa]
1	50950	5.1	50081	3.1	42800	153	53216	148
2	100109	4.3	103211	2.7	71216	150	97200	141
3	134480	3.5	125000	2.6	104203	142	180304	135
4	180500	3.1	203400	2.4	150400	131	228096	120
5	315000	2.6	366009	2.1	275000	104	313801	88
6	430000	2.2	460041	1.8	321881	91	418093	80
7	600310	1.9	571004	1.5	404000	86	603200	71
8	800900	1.7	850030	1.3	603040	68	817204	62
9	1004301	1.6	1049996	1.0	1112000	42	1040200	44



a b

Fig. 11 - S-N curves (square - no chemical corrosion, circle - specimens subjected to chemical corrosion); a) specimens with bonded joints, b) specimens with bonded joints and screw and nut / *Diagrame de rezistență la oboseală (pătrat-fără coroziune, cerc-epruvete supuse la coroziune chimică) ; a) epruvete îmbinate prin lipire, b) epruvete îmbinate cu adeziv şi şurub*

7.2 Tests to determine the fatigue strength of the joints between parts of composites

Batches of six specimens were used, § 3, Figure 5 b,c, having thickness of 5 mm, half of them were not subjected to chemical corrosion and the other half were subjected to chemical corrosion by keeping them for 30 days in a solution of NaOH 3.5%. The tests revealed the following results [11,12] in Table 4.

After analysing the results and approximating with an exponential the S-N curves (Wöhler curves) for joints were obtained, Figure 11.

8. Conclusions

- The presented method by using the designed equipment does simultaneous fatigue testing by applying repeated stress cycle load, of a batch comprised of six samples in the same conditions. This reduces the time needed for testing by 6 and reduces the scattering range of experimental results.

- The frequency of a repeated stress (0 to max) cycle load complies with maximum 10 Hz required for testing this type of material. Thus, the heat generated due to friction within the material does not affect the fatigue strength.

- The presented method can be used for fatigue testing by applying repeated stress cycle load to any type of composite respectively matrix type/ reinforcement provided that the samples meet the standard requirements presented in §5.

- The equipment, through the chosen kinematic chain, is energy efficient because specimens, that loosen help to the extent of other specimens.

- Tests carried out demonstrate, through the achieved results, the correct operation of the testing equipment. The S-N curves are consistent with those obtained by other authors for steel specimens when applying repeated stress cycle load and is highlighted the influence of corrosion on both the material and the joints.

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MANIFESTĂRI ŞTIIŢIFICE / SCIENTIFIC EVENTS

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