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Analysis of composite structural elements

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Properties

ABSTRACT

Purpose: The themes of the study are composite structural components. For this purpose have been designed and built several research positions.
Design/methodology/approach: Using different structural materials to build new device components requires multiple tests of the components. Research posts were designed in the advanced graphical program CAx Siemens NX 7.5. Analysed samples were made from the glass fibre, aramid and carbon of various weights. Due to the specific use of composite materials it focuses on the elements in the form of plates and flat bars. For the examination of experimental strain gauge technique was used bead, the force sensor and displacement sensor. The experimental methods were compared with computer simulation using the FEM.
Findings: The aim of this study was to determine the basic material constants and a comparison of the experimental method and the method of computer simulation.
Research limitations/implications: Change the number of layers and how to connect the laminate with the steel plate changes mechanical properties of the structural component.
Practical implications: The ultimate result will be knowledge on the different forms of laminates, such as material properties, the stresses in all layers, strain and comparing the results obtained by two methods.
Originality/value: The expected outcome of the study will be the composition and method of joining composite laminate with a steel plate to the possible application in the repair and construction of structural elements of freight wagons.
Keywords: Composites; Mechanical properties; CAD/CAM; Engineering design; Materials design

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1. Introduction

Implementation of research and development project PBR8/RMT2 titled: „examine and analyse the properties and establish conditions for formation of geometric features and material components necessary for the innovative design of freight wagons", entailed the necessity of testing structural components formed on the basis of fibre composites.

The project aims to propose the use of glass laminates in the matrix resin to repair damaged structural components of the wagon body rail. The process of forming geometrical shape and the material was divided into two processes of research and analysis. The article presents two research positions, which have been designed in advanced graphics program CAx Siemens NX 7.5 and built. Then a series of tests were performed of composite structural elements in the form of plates and flat bars [12-16].

The present quite dynamic course of technology is causing the need to seek new structural materials with different and impossible to obtain with traditional materials. The group of materials are becoming more widely used may include various types of composite materials. Their intensive development dates back to 1960 years of the twentieth century, when it began to use multi-layer polymer fibre composites, called laminates. Structures which were made using this technology compared to traditional materials are characterized by a much smaller weight and can have perfect strength parameters. Therefore they are finding wide applying in such fields at present as: aerospace, automotive, shipbuilding, manufacture of sports equipment and more [1, 2, 3, 4,].

There are several factors which affect their virtual and shape parameters that are affected by, among on following factors:

- the type and quality combined with each component,
- adequate and properly implemented technology,
- correctness of the design-cycle calculation [3,4].

Flexibility in shaping the parameters of composites makes it practically every structure made in this technology requires an individual design process of composite material. This leads to the formation of a variety of materials, the detailed characteristics such as elastic constant and strength characteristics should be known before applying them. It should also be noted that the change of geometric characteristics of the composite material can cause a change in its mechanical properties and may even receive additional sheet. Each of the newly formed composite requires individual examination designed to determine its basic characteristics such as strength and elastic. Before joining the design, process of composite structural elements needs to specify the following properties:

- breaking strain,
- elongation at break,
- flexural strength,
- compressive strength,
- resistance to dynamic loads,
- endurance time,
- hardness,
- flammability [7-11].

The process of research and analysis of structural elements made of composites are divided into two separate processes. The first closely linked to computer modelling and simulation, and the second related to the experimental tests performed on the bench.

2. Modelling of composite materials

Modelling of composite construction can be accomplished in two ways. The first model based approach to solid modelling, using the function block. Thus created a model to define the thickness of the composite element. The target thickness is not a value binding during the modelling of the laminate in a later stage. If there are a few need to perform a structural analysis of the isolated element is possible through modelling, using a type of shell, assuming - in the form of geometric - zero wall thickness.

Laminate Modeller command set is available in the Advanced Simulation Module. In order to analyse the composite must run NEW FEM and Simulation, and properly configure the entire process of simulation.

Carrying out the process of computer analysis encountered a serious problem; in the library of materials NX 7.5 has not included the material properties of the materials used to conduct experimental research. Was required in the first instance to allow experimental studies to define these parameters, such as Young's modulus, Poisson ratio, and density (the latter of which could already be determined on the basis of the materials used in the manufacture of laminates) [12, 13,15, 16].

The key steps of modelling the laminate are shown in Figure 1. After the simulation achieved the following types of results for the entire sample:

- Nodal Displacement,
- Nodal rotation,
- Reaction Force
- Reaction Moment

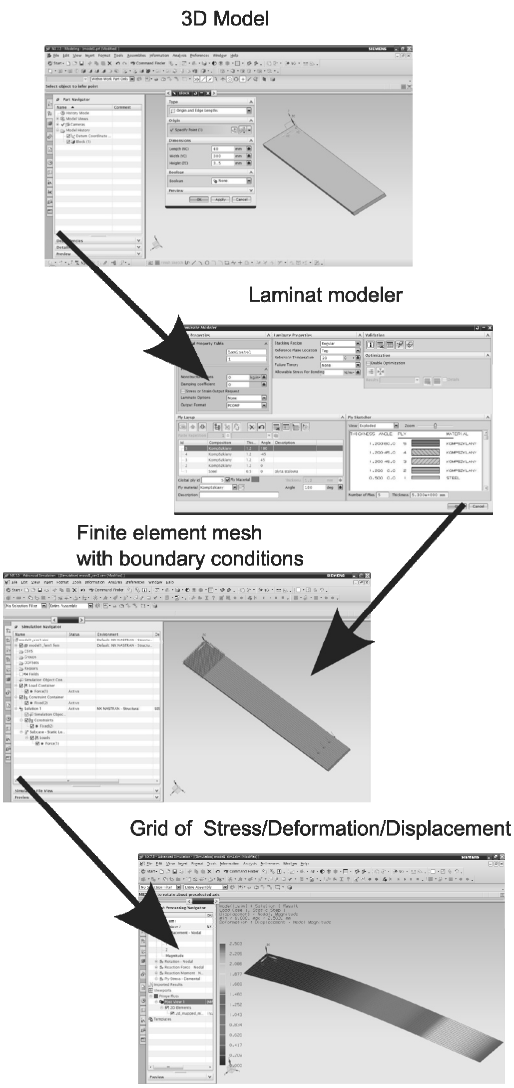


Fig. 1. Laminat modelling steps

In detail, it is possible to analyse stress in individual layers of the laminate and so types of results are as follows:

- Regardless of the direction XX, YY, ZZ, XY, YZ, ZX,
- Determinants,
- Mean,
- Max Shear,
- Min principal,
- Mid principal,
- Max principal,
- Octahedral,
- Von-Mises.

Using the command Identify the results has been read in places where the strain gauges were placed on the manufactured samples.

3. Experimental method

Using strain gauges strain measurements are made of solids. In practice, laboratory measurement of strain is limited mostly to measure the elongation of the body surface. This follows directly from the characteristic of measuring instruments as well as the fact that the extreme values of strain (stress) occur on the surface of the body. Measurements of strain inside the body, due to their cumbersome, takes place very rarely.

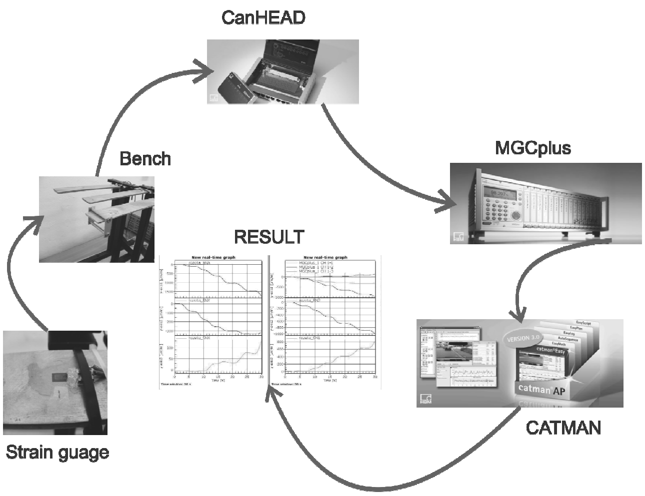


Fig. 2. Measurement chain

In measuring systems used in measuring the strain gauge method can distinguish the following elements [5, 6, 12, 16]:

- power source - in the form of Power generator
- bridge strain gauge - a set of four strain gauges connected in a Wheatstone bridge circuit,
- amplifier - an increasing volume of the sensor signal without distortion,
- recorder - recording equipment.

In order to carry out the measurements were used:

- Laboratory manual universal amplifier HBM MGCPLUS, with an appropriate card for connecting measuring strain gauge bridge, constructed of four strain gauges,
- CANHEAD - 10-channel amplifier modules for installation close to measuring points. The distributed amplifier system for structural testing and experimental stress analysis,
- A set of sensors - Force transducer U2B with the maximum load force up to 50kN, displacement sensor WA-L-20 mm, Strain gauges - TF-5/120 from TENMEX.

Overriding Software installed on a PC, managed the entire process of measuring. DAQ Software CATMAN was supplied by HBM and allowed the setting up of measuring equipment and data collection and presents them in graphs. Figure 2 presents a complete measurement chain [12].

The sensors were mounted on the bench; strain gauges were placed on samples in specific locations. For samples in the form of flats were used to measure a single strain gauge, measuring the strain only in one axis. In the case of laminated plates the sensor has been made from three strain gauges (Fig. 3) arranged in one plane, as close to each other as possible, building a rosette in the system 0°/45°/90°. In this configuration, it is possible to measure the stress in the X, Y, and XY axis direction, ultimately resulting in reduced stress Von Mises [5, 6].

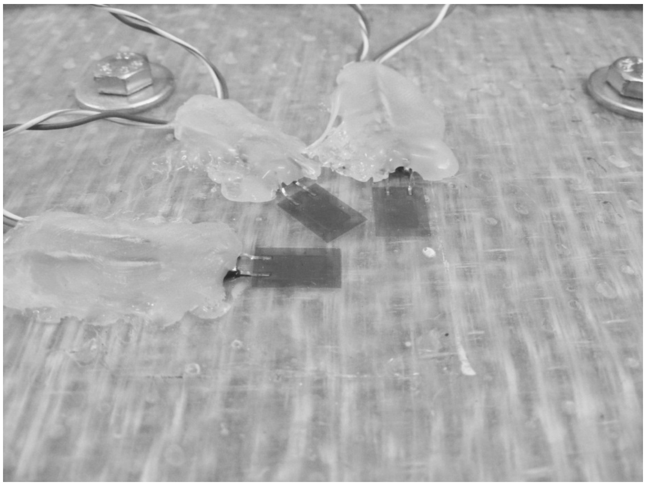


Fig. 3. Strain gauges on a surface

4. Research positions

For the test it was necessary to design and execution of research positions. The primary objectives of construction of individual positions were:

- Ability to perform fatigue tests, with adjustable frequency and amplitude excitations,
- Feasibility studies and the bending and tensile specimens in the form of flat bars,
- Possibility of carrying out tests on laminated plates using force acting in the middle of the plate [12-14].

Finally, proposed three types of positions, which were ultimately made. The first is a test of fatigue (Fig. 4). It was constructed of four parts:

- Mounting plate,
- Mounting arrangement - rigid steel frame to which the test samples are mounted and hand forces,
- The system forces - with attached cam shaft, with adjustable amplitude excitation,
- Propulsion system - the engine to the drive.

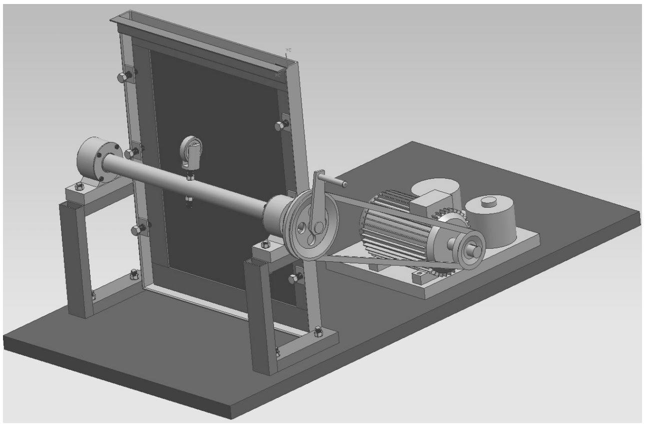


Fig. 4. Fatigue test stand

Another position allows to perform two kinds of research. By selecting a suitable method of mounting the samples, possible three-point bending tests carried out and axial loading laminate panels.

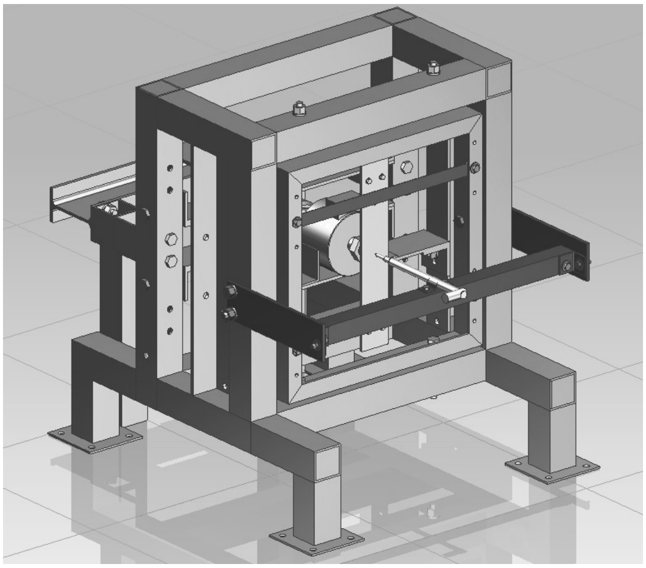


Fig. 5. Three - point bending position

Three-point bending test (Figs. 5-6) is carried out in accordance with PN-EN ISO 178. It is used to determine parameters such as flexural strength, modulus of bending and other features resulting from the dependence stress/strain. Materials that can be tested in accordance with the schedule specified in the standard include: thermoplastics and thermosetting plastics. The method used in this standard describes the recommended dimensions of fittings for research and alternative dimensions. For studies on the profiles that differ from the recommended results obtained may not be comparable.

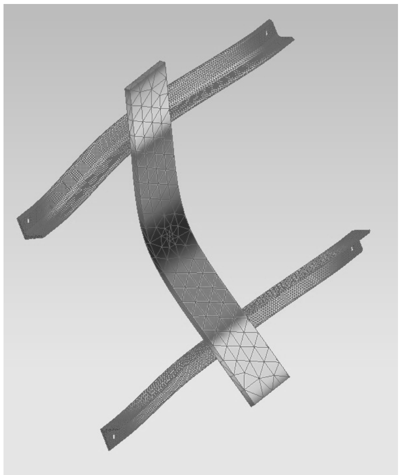


Fig. 6. Simulation of the test

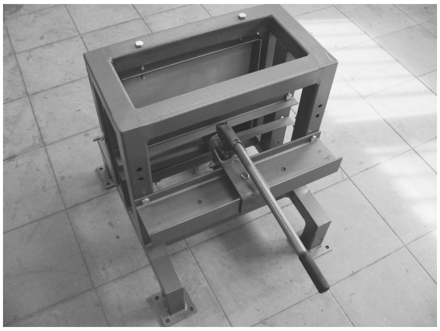


Fig. 7. Research position for axial loading laminate panels

Fig. 8. research position for axial loading laminate panels with sample and the sensors

By changing the configuration of the position, by changing the attachment is possible to carry out tests on laminate panels (Fig. 7). The use of force and displacement sensors, allows an analysis of displacement of the disc surface relative to the power with which they work on a sample. In addition, strain gauges (Fig. 8) applied to investigate the possible deformation of the sample surface.

Last position was to fulfill the function of the position of the tensile samples were designed and constructed (Fig. 9). For the tensile specimens used in hydraulic cylinder with hand pump. To measure the force with which the sample was expanded uses a force transducer, the transducer was used to measure the elongation of the sample elongation.

Position was used to determine the material constants of composite samples. Data obtained from the study were later used for computer simulation.

The most important criterion when designing the position was to find the appropriate stiffness and strength of individual structural elements during the test. Sample holder assembly was designed in accordance with PN-EN ISO 527 (Fig. 10).

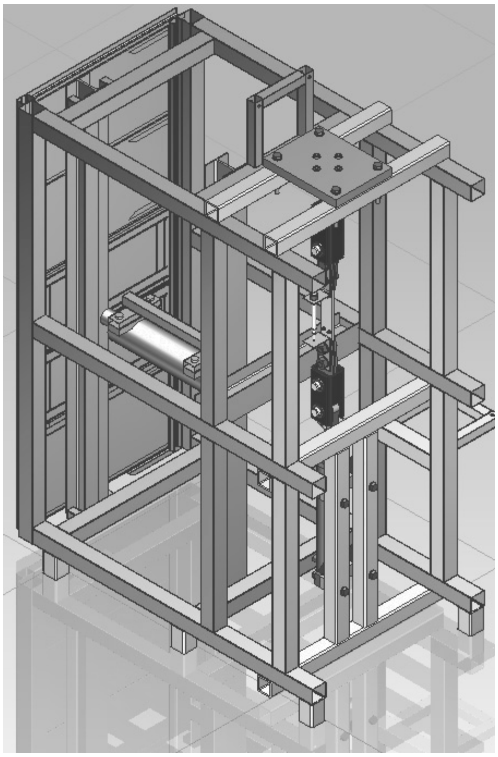


Fig. 9. The position of the tensile

5. Property research

The scope of research included fabrics: glass, aramid, carbon of various weights and weaves. The aim was to create a library of material properties to carry out computer simulation and experimental verification of the difference between the different configurations of the laminate. From each laminate sample was performed in a flat in order to examine the bending and stretching, and in the form of laminated panels.

The diversity of samples consisted of still using two different resins:

- Epoxy – Epidian 6 with hardener PAC (combination of 100 units of resin to hardener of about 80 units),
- Polyester - Polimal 1094 with hardener Luperox K1 (a mixture of 100 units resin to 1 unit of hardener).

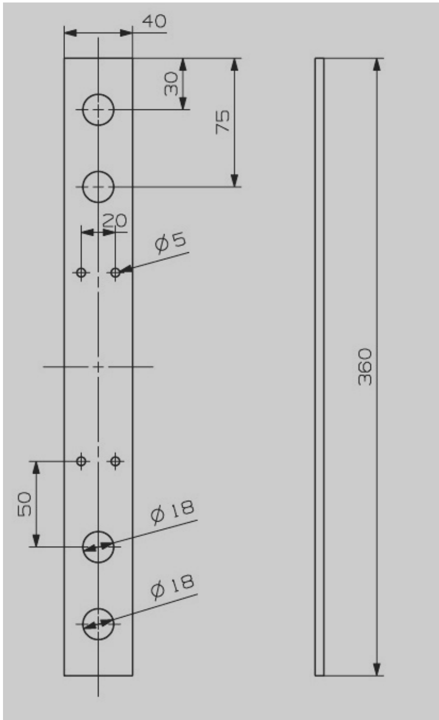
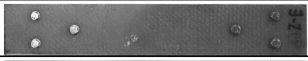
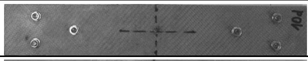
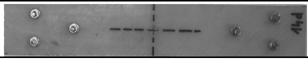
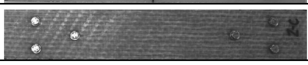
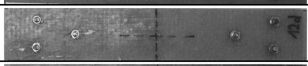
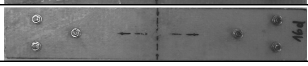


Fig. 10. The dimensions of the sample

Samples were made by contact method. This process takes place in several stages and is characterized by high labour intensity and time-consuming. In order to maintain the required quality of the laminate, and thus the proper strength, it is necessary to maintain a high duty of care to carry out the lamination process. Therefore, in the exercise samples for special attention to preserve the relative proportions of reinforcement and matrix resin proper filtration fabrics and reducing the formation of bubbles in the matrix. In the first place was covered with mould release agents (in liquid wax and polyvinyl alcohol), which facilitated the further stage of separation of laminate from the mould.

Seepage of resin through the fabric was performed using a metal roller, taking care not to damage the fabric weave through too strong a compression of the shaft. Amount of resin destined for one laminated was divided into two parts. Approximately 60% of resin was placed on the pants, each layer, the remaining 40% of the top layer of filtering. Thus prepared sample was left by a certain time at room temperature until it is completely bound by the resin. The procedure was repeated performance of the laminate during the manufacture of further samples required for the test bench. Specimens for bend tests are presented in Table 1.

Table 1.
Sample to perform bend tests

Glass fiber 290 g/m^2 – Epidian 6	
Roving fiber 1000 g/m^2 – Epidian 6	
Glass fiber 450 g/m^2 – Epidian 6	
Roving fiber 400 g/m^2 – Epidian 6	
Glass fiber 290 g/m^2 – Polimal 1094	
Roving fiber 1000 g/m^2 – Polimal 1094	
Glass fiber 450 g/m^2 – Polimal 1094	
Roving fiber 400 g/m^2 – Polimal 1094	

6. Results of this study

The result of tests carried out on the bench is a collection of charts showing all the parameters measured during the tests. The results obtained differ in the amount of measured values, a kind of measured values, number of tests performed. The results obtained allowed us to make a comparison of materials in the interest of researchers. Due to the limited capacity of the article only showing exemplary results.

In the three-point bending test, each sample was subjected to force loading at which the value of the deflection was 1.5 mm. The study was conducted at the deflection values, because it allowed the examination of all samples without damaging them. In the case of too little deflection, mainly in samples characterized by a greater thickness of the present force was too small to enable them to properly register the force sensor (lower range). However, in the case of a larger deflection observed plastic deformation of samples of small thickness, tested at a small spacing between the supports. Samples were observed in which the plastic deformation caused replaced with new as they could be damaged layers of reinforcement. In effect, this would affect the results of measurements.

In the Figures 11-12 are presenting exemplary plots of forces and displacements. In the Figure 11. is presented a test on a sample made from glass fibre 290 g/m^2 with a resin of epoxy. One the second figure (Fig. 12.) shows the results of tests on glass fibre 290 g/m^2 with a resin of polyester.

After changing the method of attachment, performed tests of laminate panels combined with steel sheet. The process of investigation included examination of the degree of the impact of changes in the number and diameter of the rivets on the properties of the samples in the form of composite plates with dimensions 300x400 mm, in combination with the steel sheet. Items that have been modified to: the method of attachment of samples and also taking into account the measurement of deformations, at a specified location, using a strain gauge rosettes, made up of three strain gauges in the configuration of 0 ° / 45 ° / 90 °.

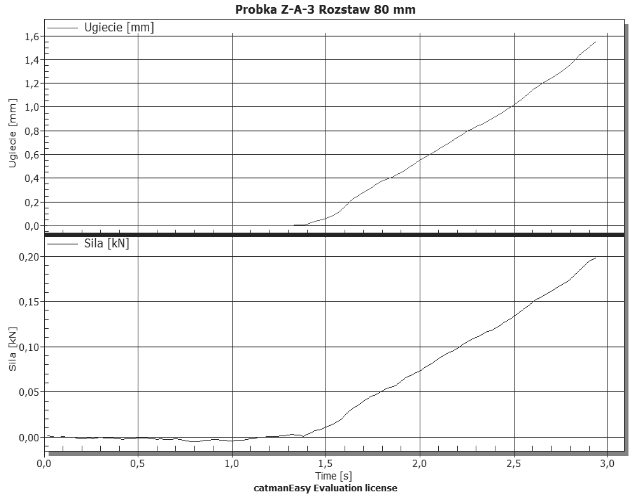


Fig. 11. Glass fibre 290 g/m^2 with a resin of epoxy

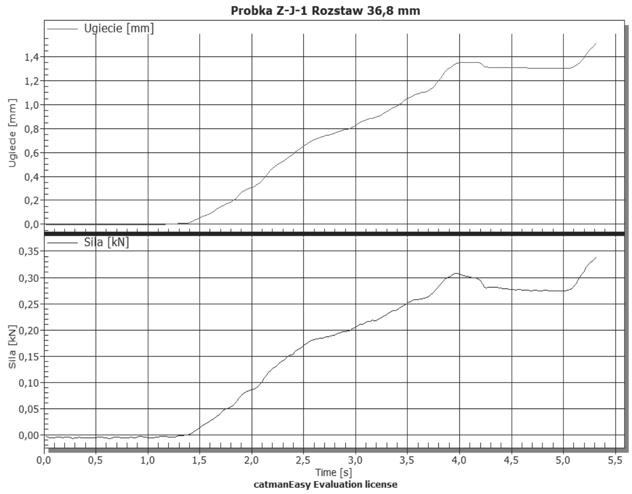


Fig. 12. Glass fibre 290 g/m^2 with a resin of polyester

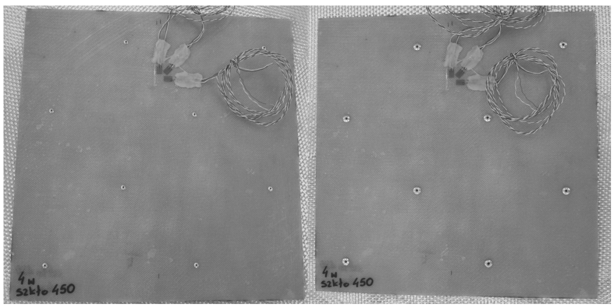


Fig. 13. Samples PR1 i PR2

Table 2.
The results of the comparison samples PR1 and PR2

	F[kN]	0.33	0.66	1		F[kN]	0.33	0.66	1
PR1	ε0 [μm/m]	-195.35	-192.60	-289.59	PR2	ε0 [μm/m]	-222.61	-275.34	-304.02
	ε90[μm/m]	108.19	103.05	154.11		ε90[μm/m]	279.28	360.44	422.47
	ε45[μm/m]	-13.17	-15.51	-35.13		ε45[μm/m]	43.54	46.62	42.36
	Frz[N]	0.330	0.653	1.034		Frz[N]	0.33	0.663	1.00
	εmax[μm/m]	111.18	105.89	156.46		εmax[μm/m]	279.71	360.42	422.81
	εmin[μm/m]	-198.34	-195.44	-291.94		εmin[μm/m]	-223.03	-275.32	-304.36
	αg[°]	-27.23	-27.24	-27.48		αg[°]	-27.89	-28.1	-28.36
	γxy[μm/m]	424.92	414.21	632.96		γxy[μm/m]	737.64	949.60	1106.61

The samples PR1 and PR2 (Fig. 13) are made of a laminate formed of four layers of fiberglass fabric with a weight of 450g/m^2 combined with steel plate with a thickness of 0.5 mm using eight blind rivets with protruding head, with a torn spinal. The sample used PR1 head rivets with a diameter of 3 mm, and PR2 were used rivet head diameter of 4.8 mm. The results of the study are presented in Table 2.

Conducting the research on the fatigue bench were carried out in two stages. The first stage consisted of validating the assumptions that had to be carried out on the bench. Using the hand crank made a few cycles, making sure that all sensors are functioning properly. Then the analysis was to find the amplitude of the whole system work. It was necessary to establish the frequency to set the inverter so that the shaft speed does not exceed the maximum measurement frequency of the measuring system.

To carry out the measurements used the following sensors: displacement sensor, which measures the deflection of laminated plates under the influence of force and strain gauge arranged in rosettes. The results are summarized in a graph and table.

One of the samples analyzed is a four-ply laminate made of glass fiber plain weave with a weight of 280 ± 5% [g/m^2], the thickness of the fabric 0.28 ± 15% [mm]. The sample has been deformed by the cam by hand with a small frequency. The results of the study are presented in Figures 14, 15.

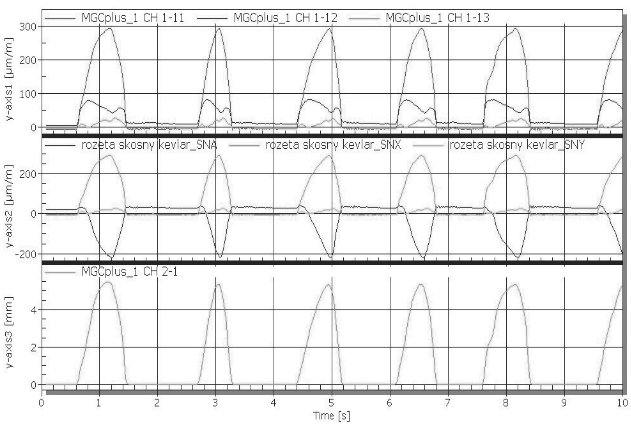


Fig. 14. The graph shows the deformation of a composite sample of glass fiber, plain weave, founded 5 mm displacement

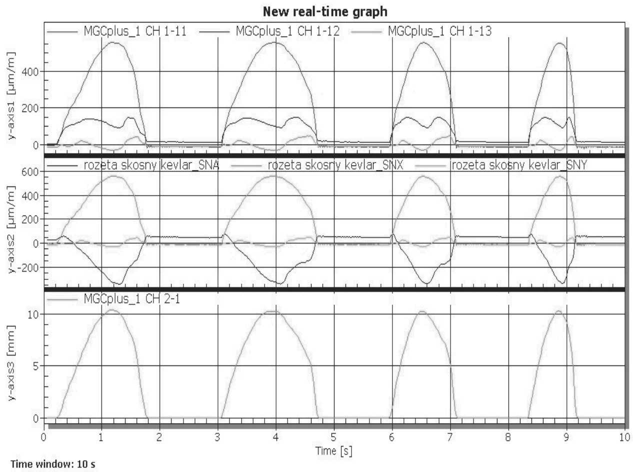


Fig. 15. The graph shows the deformation of a composite sample of glass fiber, plain weave, founded 10 mm displacement

For comparison is shown in Figure 15 the same sample, but the answer was 10 mm displacement. You can see much greater strain and increased strain plate surface by nearly 30%.

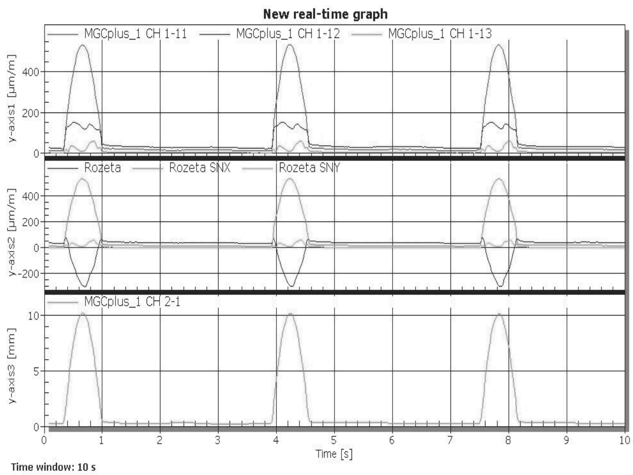


Fig. 16. The graph shows the deformation of a composite sample of glass fiber, plain weave, which was founded 10 mm displacement and 18 rpm

The final form of testing was to run the propulsion system, which was designed to automate the process of fatigue tests. There were performed several tests with different values of speed. Tests were performed in the range of 18 to 102 rpm. Interpretation of the results presented in the form of graphs (Figs. 16, 17).

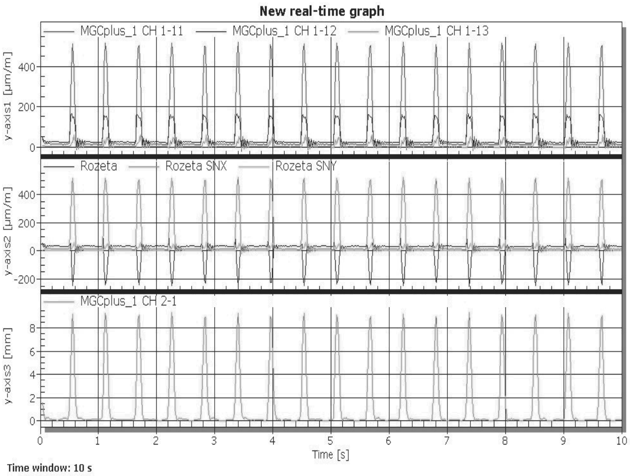


Fig. 17. The graph shows the deformation of a composite sample of glass fiber, plain weave, which was founded 10 mm displacement and 102 rpm

7. Conclusions

Conducting a series of tests made it possible to build a library of material properties. This in turn allowed an experimental verification of computer simulation research. For each bench formed separate proposals.

7.1. The position of the fatigue tests

The work examined samples taken from six types of materials using the experimental method. Tests were conducted on designed and built position. The samples were examined by means of strain gauges.

The analysis of samples at a given displacement of 5 mm to 20 mm, allowed the extension designates the individual materials. During the test composite samples was noted that the highest flexural strength materials are characterized by the highest weight and maximum thickness.

The results of measurements of elongation of individual materials at the same value movements depend on the speed. It was found that the higher the rotational speed of the shaft on which is mounted a cam that reduces the accuracy. It was noted that minimal differences elongation of 0.5% to 1% occurring on the speed of 18 rpm to 72 rpm over the values of rotation, strain reaches values of up to 30%.

7.2. The test stand for tension and bending of composite samples

The highest value of flexural modulus has a sample consisting of flat steel and composite, the reinforcement was made of cloth roving weighing 1000 g/m^2 in a matrix of epoxy resin Epidian 6th. The lowest value was observed in the case of a sample consisting of a steel flat bar and two layers of composite material, reinforced with glass cloth with a layer of aluminium with a weight of 290 g/m^2, in a matrix of epoxy resin Epidian 6th.

When comparing the samples consist of two (composite steel flat bar) or three layers (two layers of composite steel flat bar) higher values of the linear elastic modulus, and therefore have better strength properties of the sample consisting of two layers.

To a large extent reduced the strength properties of three-layer samples may be due to insufficient load-carrying the bolt connection.

In most cases, samples having a matrix of polyester resin have better strength properties. The exception is the roving fabric reinforced sample weight 1000 g/m^2 in 1000 for which, better properties are obtained using epoxy resin.

Acknowledgements

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