697. Testing composite materials connected in bolt joints

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Abstract. The following work contains the basic information on the composite materials connected in bolt joints. It is presented the most important methods of strength testing of such a type materials. The way of performing tests using the strain gages measurements is also presented. The work describes the findings of strain gages measurements performed on the composite structure samples. The samples are bolt joined and the connection of laminate and steel sheet is provided. Additionally the simulations of performed tests are made using the Unigraphics NX7 software by the finite element method. The results of the simulations are compared with the results of empirical measurements.

Keywords: composite materials, bolt connection, strain gauge, sandwich composite, deformation.

Introduction

Mechanical and physical properties of fibrous composite materials are very good in comparison with other constructional materials. The major advantages of this type of materials are low weight and high strength [1, 2, 6, 7]. Machines and mechanisms compound with composite materials have much less weight than traditional constructions. A very serious weakness of composite materials is the way of jointing composite materials with other materials such as steel. The methods used to join composite to steel and composite-to-alloy are unreliable. There are three types of joints used in composite engineering: adhesive joints, screw joints and integrated joints. The first two types of joints are most common in all kinds of technical applications [1, 2, 7].

Tested specimens

In this paper the results of analysis of many different specimens will be presented. The tested specimens are made with composite materials reinforced with fiberglass, carbon fibers and Kevlar fibers (Fig. 1). Epidian 6 and Polimal 1094 resins were used for manufacturing specimens Polimal 1094 is constructional resin, on average the flexible, accelerating agent with low vinyl benzene emission [3].

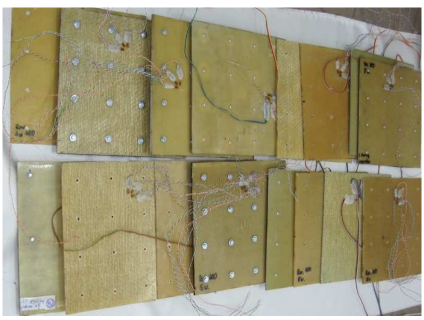

Fig. 1. Analyzed specimens with electric resistance wire strain gauges

The considered composites are the hybrid ones and sandwitch ones, because of a connection between laminates and steel platter.

Numerical simulation

For a numerical simulation (Fig. 2) the Unigraphics NX environment was used. Modelling of a composite requires the creation of a geometrical model of the analyzed system. Modelling of the composite in the Unigraphics makes possible setting parameters for each ply of the laminate [6-8]. In the Unigraphics one can set parameters such as: ply material, thickness or angle of ply and nesting consecutive ply in every layer, making different structure from each layer. The user can also define parameters such as: matrix material - reinforcements layer, matrix volume fraction, warp fiber material, weft fiber angle, weft fiber material, and finished thickness.

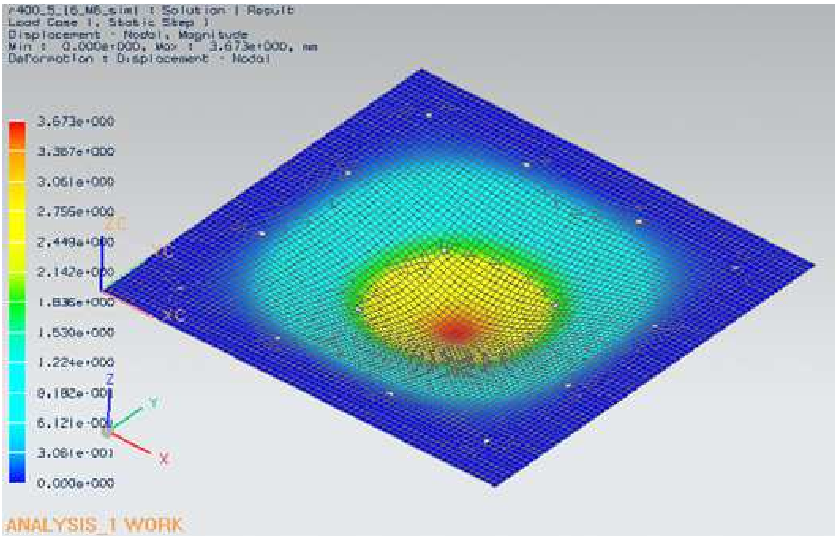

Fig. 2. Sample numerical simulation results

The obtained results are compared with a numerical simulation in the Unigraphics NX environment. Numerical simulations are reusable and can facilitate the designing process, but in many cases the results obtained from this method are imprecise.

Measurements techniques

As the main measurements techniques, the method using the electric resistance wire strain gauges. The electric resistance wire strain gauge method rule is based on the well-known physical properties of made of metal wire, the point is that the electrical resistance of the metal wire is the function of its length. If the metal wire is stretched within the limits of its elasticity and become narrower or longer, then increase its electrical resistance end-to-end. This can be used in testing of materials, strain measurements of different machines, mechanisms and constructional elements. Between the electric resistance R and its change ΔR and the unitary strain ε the following can be written:

$$\frac{\Delta R}{R} = k\varepsilon, \tag{1}$$

or

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$$\varepsilon = \frac{1}{k}\frac{\Delta R}{R}, \tag{2}$$

where k – the constant of extensometer.

The constant of the extensometer depends on the type of material used for building the wire sensor and this constant vary between 1,6÷3,6 for most common applied alloys. This constant is also called the coefficient of strain sensitivity. In accordance to the Hooke's law the intensity of stress can be estimated in the testing cross-section as:

$$\sigma = E\varepsilon = \frac{E}{k}\frac{\Delta R}{R}, \tag{3}$$

where E – the Young modulus.

As we can see the measurement of the length of the element is sufficient. The one should know the Young modulus and the geometrical parameters of the element to determine the loading force [4-5]. Most common electric resistance wire strain gauges are: tortuous, lattice and foil ones. The foil extensometers can be listed as:

– one axis extensometer (Fig. 3, a) – most common used extensometers for testing of bending or stretching strains,
– two axes extensometer (Fig. 3, b) – used for measurements in two directions – e.g. the external area of the jacket in the cylindrical vessels – with the axle base equals 90º, for measurements of the torsional moment in drive shafts – the axle base equals 45º in relation to the axis of the shaft,
– three axes extensometer (Fig. 3, c), so called strain rosette – mensuration in the three axes directions every 120 degrees – for the area of unknown directions of the stress or for testing the membranes,
– four axes extensometer (Fig. 3, d), for shearing stress mensuration, for strain mensuration of membranes endanger for shock pressure.

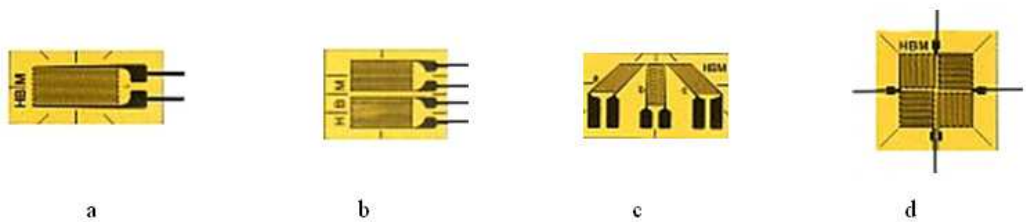


Fig. 3. Sorts of the electric resistance wire strain gauge from the HBM company [4]

Apart from these types there are also the special extensometers with construction adopted to the character of measured values, for example the extensometer for measurements of torsional shafts strains. In the case of biaxial state of stress, the three directions of measurements are needed to estimate the principal stress values and their directions. Therefore the strain rosette is one of the most common way used in practice. In such a type case, values of the principal stress can be derived with the well-known formulas as follows:

$$\varepsilon_{\max} = \frac{\varepsilon_0 + \varepsilon_{90}}{2} + \frac{\sqrt{2}}{2}\sqrt{(\varepsilon_0 - \varepsilon_{45})^2 + (\varepsilon_{45} - \varepsilon_{90})^2}, \tag{4}$$

$$\varepsilon_{\min} = \frac{\varepsilon_0 + \varepsilon_{90}}{2} - \frac{\sqrt{2}}{2}\sqrt{(\varepsilon_0 - \varepsilon_{45})^2 + (\varepsilon_{45} - \varepsilon_{90})^2}. \tag{5}$$

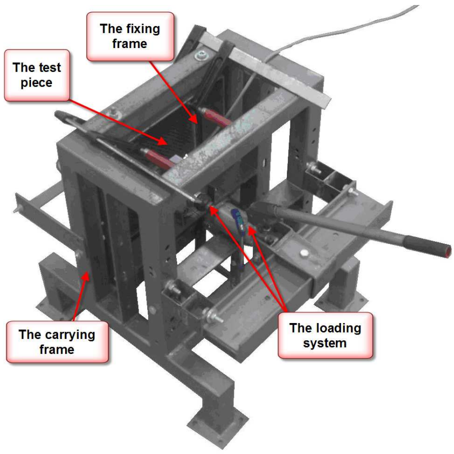
Basing on the measured values of strains in three different directions the calculation of the non-dilatation strain angle is possible. This angle is proportional to the shear stress in range of the elastic strains. This relation can be written as:

$$\gamma_{xy} = 2\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90}) \,. \tag{6}$$

The angle between the direction of the principal stress and the assumed axis x (from where the strain ε_0 is measured) has the following form:

$$tg 2\alpha_g = \frac{2\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90})}{\varepsilon_0 - \varepsilon_{90}} \,. \tag{7}$$

The tests were provided on the laboratory stand at the Silesian University of Technology in Gliwice, Institute of Automation of Technological Processes and Integrated Manufacturing Systems, Poland presented in figure 4.



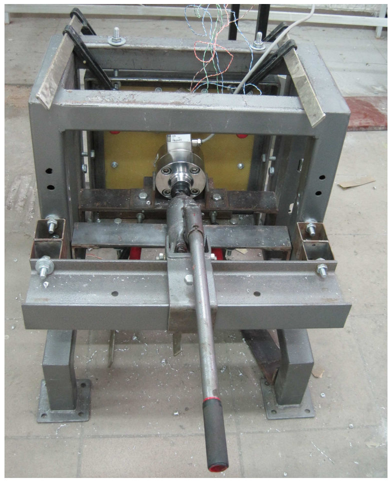


Fig. 4. The picture of a laboratory stand with the displacement sensors and loading systems

The laboratory stand is built up of a carrying frame, fixing frames, actuators and measurement elements. The stand is equipped with the force gauge (Fig. 5) and the displacement sensor. In figure 5 the force gauge and the hydraulic motor operator are presented. Between the sample and the actuator, the dynamometer is located. The laboratory stand can be used for the static and dynamic measurements. The performed measurements are the static ones.

Exemplary results of the experimental tests

In this section in tables the results of the experimental tests are given. The values of the loading force F and the measured real force F_r are collated. The readout strains from three extensometers of the strain rosette and calculated strains: the principal one, the maximal and minimal ones are shown. The non-dilatation stress angel γ_{xy} and α_g. In table 2 the results for R400_5 specimen (five layers sample the roving made with GSM 400g/m2) are presented.

Table 1. Results of the experimental tests of the R400_5 sample

F	ε_0	ε_{90}	ε_{45}	F_r	ε_{max}	ε_{min}	α_g	γ_{xy}
[kN]	[μm/m]	[μm/m]	[μm/m]	[N]	[μm/m]	[μm/m]	[°]	[μm/m]
0,33	-159,69	128,95	145,96	331,4	201,05	-231,8	-21,6	271,63
0,66	-224,57	178,87	240,32	675,9	308,69	-354,39	-20,0	341,98
1	-238,11	202,76	311,70	1036,5	378,6	-413,96	-16,5	331,93

In Figure 5 the characteristics of the strains in the time function are presented. The charts were generated in the Catman software from the HBM and the MS Excel based on the obtained data. First chart presents the measured strains from three extensometers one at a time. The strain ε_0 is marked by a red color line, the strain ε_{90} by a blue line and the strain ε_{45} by a green line. Second chart presents the measured force in the time function and the last one is the non-dilatation stress angle in the time function.

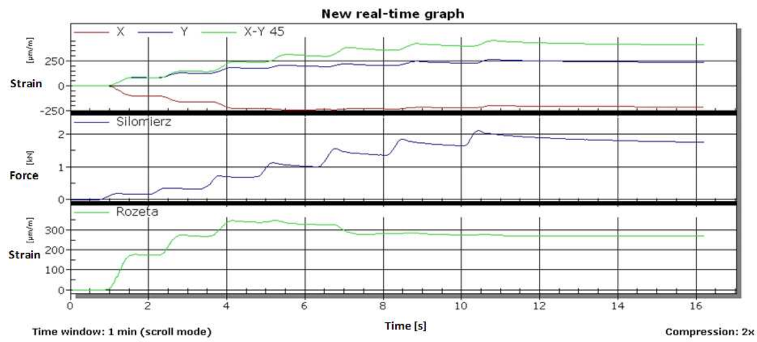


Fig. 5. Characteristic of the strains and the force in function of the time (R400_5)

In Figure 6 the chart of calculated strains (the minimal and maximal principal stress) in the time function is presented.

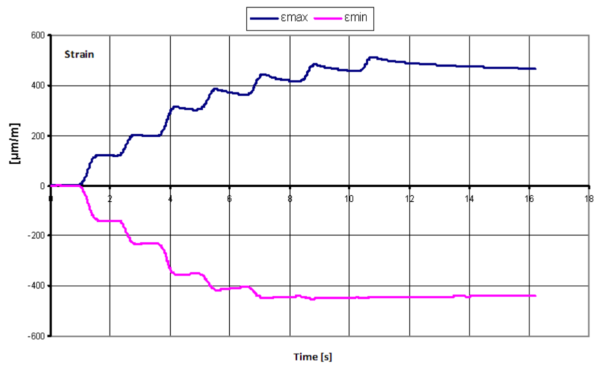


Fig. 6. Chart of the minimal and maximal strains in the time function (R400_5)

In the presented case (R400_5) the minimal and maximal strains have similar values of course only with contrary sign but after overflowing 1000N value of the force decrease of the non-dilatation stress angle can be observed.

Conclusions

The considered test pieces are laminates and composites. The laminates are jointed in an adhesive way. The considered composites are both the steel-laminate hybrid and the steel-laminate sandwich. The steel laminate sandwich is screw jointed. In this work there are the results of testing fibrous composite materials connected in bolt joints, shape joints and adhesive joints presented. Composite materials reinforced with fiberglass, carbon and Kevlar fibers are considered. The tested samples are handmade and ones have some heterogeneities in laminates that can provide some result errors and distinctions between the results obtained in theoretical and practical ways. The arrangement of reinforcement fibers is a very important issue. For manufacturing of specimens the Polimal 1094 and the Epidian 6 resins are used. The Polimal

1094 resin as distinguished from the Epidian 6 resin has better processing features. The Polimal resin is a very infiltrating one. It efficiently cuts down the time of infiltrating reinforcements fibers. The sample should be adequately prepared on the whole surface. The screw joint of the laminate and the steel plate is inadequate and provides some discrepancy of displacements. Therefore the strength properties are not so strong as they could be. The results confirm better properties of the joint samples joint with the higher number of the applied screws and lower displacements of such a type of realizations. The difference between the Young modulus of the connected laminates and steel plates may cause the destruction of elements. A major problem of modeling and simulating the composite materials in numerical environments is assuming physical and material parameters of the analyzed elements. In literature there is some discrepancy between individual values, the producers of woven fabric do not provide any important values and parameters. Numerical simulations permit testing of impact on strength properties. In this type of modeling the most important are the boundary conditions and properly assumed finite elements (FEM) providing an appropriate reflection of warp and fibers. Handmade specimens have different participation of warp and reinforcement fibers but the results of testing on resin impact cause no impact in this aspect. Based on the obtained results, the lowest displacement was for composite materials with carbon fibers. This type of reinforcement has high strength properties and low mass density. The presented results for combination of laminates and steel plates can be used for many different types of containers, freight and goods wagons, especially for applications where the welded joint is needful.

Acknowledgements

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