Carbon fiber based composites stress analysis. Experimental and computer comparative studies

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Abstract. Composite materials used nowadays for the production of composites are the result of advanced research. This allows assuming that they are among the most elaborate tech products of our century. That fact is evidenced by the widespread use of them in the most demanding industries like aerospace and space industry. But the heterogeneous materials and their advantages have been known to mankind in ancient times and they have been used by nature for millions of years. Among the fibers used in the industry most commonly used are nylon, polyester, polypropylene, boron, metal, glass, carbon and aramid. Thanks to their physical properties last three fiber types deserve special attention. High strength to weight ratio allow the use of many industrial solutions. Composites based on carbon and glass fibers are widely used in the automotive. Aramid fibers ideal for the fashion industry where the fabric made from the fibers used to produce the protective clothing. In the paper presented issues of stress analysis of composite materials have been presented. The components of composite materials and principles of composition have been discussed. Particular attention was paid to the epoxy resins and the fabrics made from carbon fibers. The article also includes basic information about strain measurements performed on with a resistance strain gauge method. For the purpose of the laboratory tests a series of carbon - epoxy composite samples were made. For this purpose plain carbon textile was used with a weight of 200 g/mm2 and epoxy resin LG730. During laboratory strain tests described in the paper Tenmex's delta type strain rosettes were used. They were arranged in specific locations on the surface of the samples. Data acquisition preceded using HBM measurement equipment, which included measuring amplifier and measuring head. Data acquisition was performed using the Easy Catman. In order to verify the results of laboratory tests numerical studies were carried out in a computing environment, Siemens PLM NX 9.0.

1. Introduction

Composites were known to mankind for thousands of years. Already in ancient times this technology was used to prepare a composite brick as a durable building material. However, on a large scale composites have come into use relatively recently. Their tendency to manifesting different properties from the constituent materials is so desirable feature that their popularity as engineering materials is growing at a very fast pace. The effect of this phenomenon is the presence of composite materials in...
every area of daily life. These materials are at the forefront of materials used in the most developed industries, i.e. the automotive and aerospace industry, [1, 2, 5].

Composites are divided into different groups depending on the structure and the principle of composition. A specific example of composite is laminates. Reinforcement of such composite form may vary. A composites with a reinforcement made of layer of another material, long fibers, short fibers or dispersed particles can be distinguished (figure 1). A characteristic feature of laminate composites is that as matrix an adhesive binder is used. The purpose of this matrix is to maintain the shape of the composite material, to ensure protection against mechanical damage and transfer the load directly to the reinforcing material. In the case of laminates, the most common matrix material is a resin. In combination with the hardener, which is the initiator of the copolymerization process, the material forms a perfectly checking in manufacturing composites.

Despite their popularity, the composites based on carbon fabrics are unfortunately quite expensive. Carrying out laboratory tests on composites is a long-term and absorbing process. Comparative studies of actual composite samples and their numerical equivalents are intended to verify that this method is likely to replace the actual examination. Comparison of the results will verify the validity and accuracy of this method, [5, 6, 7].

During comparative studies the following course of action was adopted:
- Preparation of the composite samples and determination of measurement points on their surface;
- Construction of a fixing frame;
- Laboratory tests;
- Verification of laboratory tests results by comparing them with the results of simulation studies.

![Figure 1. Laminate reinforcement types: a) long fibers, b) short fibers, c) textile, d) layer of other material, e) dispersed particles, [3].](image)

2. Laboratory research part
For the production of the laminate a Toho Tenax HTA40 H13 3K 200TEX carbon cloth was used. It weights 200 [g / m²], and its Young's modulus is equal to 238 [GPa] (figure 2). From available types of strand a plain weave strand was selected, in which the fibers are woven with 90° angle relative to each other. As a composites matrix material an LG 730 epoxy resin was selected, which together with the HG700 initiator creates a very durable composition. The composites were cured at room temperature, which significantly lengthened the cooling process.
Samples were produced to map the area of the vehicle's body, and therefore a mold corresponding to the shape had to be produced. The material used to produce the mold was a high density S42 polyurethane foam. It was formed in the cutting process using a three-axis CNC milling machine. Developed surface characterized by a very high accuracy and quality (figure 3), [5, 12].

Laminate was produced in a manual process. The surface obtained in this type of production of the composite is slightly porous, which means that it must be properly prepared before placing strain gauges. For this purpose, the surface of the composite in the strain gauges fixing points was polished and cleaned with a special degreaser. For laboratory testing, two points on the surface of a laminate were adopted. Additionally, at the intersection of the diagonals of the top surface of the composite, an opening for fixing load was made. In laboratory studies, a Tenmex TFr-10/120 delta type strain gauge rosettes were used. Figure 4 shows a diagram of the construction of such a system. They consist of three strain gauges spaced at 120°. This system has been attached to the sample using a non-aggressive cyanoacrylate adhesive. The same type of glue is used to attach solder terminal, whose task is to separate strain gauges terminals from each other, [11].

Prepared samples were mounted in a specially constructed frame (figure 5). This solution makes it possible to restrain the test piece in a controlled manner as it is very important to make points, or surfaces of fixing properly defined. This is to avoid measurement errors during simulation studies in this area.

The block diagram of the measuring circuit is shown in figure 6. In order to obtain a reduced stress at the measuring points in the data acquisition software a virtual measurement channel was created. It allowed for immediate calculation of stress by the hypothesis von Misses by reading the stress values for each individual strain gauges of the rosette. Each of the tested composites was loaded by adding metal rings, each with a mass of 66g. These rings were mounted on the M8 hexagonal head screw with suitable nut and a total weight of 158g. Juxtaposition of weights and corresponding forces are shown in table 1. The study was carried out for the double layer and single layer composite, with a number of weights. Strain gauges rosettes were marked with numbers 1 and 2. For each of the measurements...
graphs of stresses were generated. They contained values for each individual strain gauge and reduced stress calculated according to von Mises hypothesis. Tests results included information on the reduced stress on both strain gauge rosettes.

Table 1. Number of metal rings and corresponding forces.

| Number of metal rings | 2  | 3  | 4  | 5  | 7  | 9  | 10 | 11 | 12 | 13 | 14 | 19 |
|----------------------|----|----|----|----|----|----|----|----|----|----|----|----|
| Force [N]            | 2.9| 3.56| 4.22| 4.88| 6.2| 7.52| 8.18| 8.84| 9.5 | 10.16| 10.82| 14.12|

3. Simulation research part

After the completion of laboratory research part a simulation part of examining began. The study was carried out in the Advanced Simulation module of a Siemens PLM NX 9.0 environment. Geometric model of the sample was made in the Modeling module of the same environment.

During the modelling process of the simulation sample it was very important to preserve as many of compliance with the actual sample as possible. Therefore, a model used in the modeling process was the same as the one used for the G-code generating for CNC milling machines in the mold production process. This model was also equipped with mounting surfaces corresponding to the areas fixed to the frame and areas of fixing strain gauge rosettes and applying force. In order to accurately designate these areas on a numerical model a picture of the actual sample was applied to the model (figure 7). Test object prepared so was then transferred t
The force was exerted on the surface, which corresponded to the surface covered by the screw with metal rings in the actual model. The force application direction was elected as the opposite to the Z axis. Figure 8 shows the model firmly established and loaded with the forces according to the real model used in the laboratory tests. Red arrows point to the places of force applying. The blue color represents constrained nodes of the finite element mesh.

In individual studies loading force values were set consistent with those used in laboratory studies. The simulation was performed for one- and two-layer composites. The test results are presented in the next section of this paper.

4. Results and discussion
The graphs presented in figures 9 and 10 shows the summary of series of researches which were carried out during the both test. On the chart presented on figure 9 a comparison of the average results of laboratory tests and simulation tests for rosettes No. 1 on the two-layer composite is shown. Figure 10 shows a comparison of the average results of laboratory tests and simulation tests for rosettes number 2 on the two-layer composite.

Results obtained in both types of researches do not differ significantly from each other, especially for smaller values of load. With the increase of loading force discrepancy between the results obtained in the laboratory and simulation researches increases. For the load force of 14.12 N discrepancies reaches about 20%. It is very important to note that in case of maximum force load, which is equal to 14.12 N the shape of the composite sample, has changed. After applying the force the surface transformed from convex to concave. It a drastically changed in the geometry of the sample. Such a change undoubtedly influenced the final indication of sensors.

In case of such gentle sensors like strain gauge rosettes it is very important to fix them properly. The observed differences may be due to both, the laminates structure imperfections and due to the initial stresses caused by the strain gage installation method on a sample. The results of the simulation studies showed a linear stress growth tendency. That tendency leads to a simple conclusion that they were carried out properly in this area. The drastic increase in the discrepancy between the results may be due to exceeding the linear range of applied rosettes. Linear static software simulation solver does not take into account the possibility of such a drastic change of the samples shape during the test. That situation occurred during applying a load of 14.12 N.

Worth noting is an interesting phenomenon, which was observed in both laboratory tests and simulation tests. A sudden increase of strain at a load of 3.56 N is clearly visible on both charts. This situation may be due e.g. to the geometric shape of the sample.

Figure 9. Comparison of the average results of laboratory and simulation tests.
5. Conclusions
After analyzing the results it can certainly be said that, despite some differences in the results the researches were carried out successfully. Simulation test runs much faster allowing to save a lot of time. In addition, no need of producing real samples reduces the necessary financial outlays for research. FEM stress analysis of laminates is a very good substitute for long and expensive laboratory tests.

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