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Application of feature based method in constructing innovative sheathing of railway wagons

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Analysis and modelling

ABSTRACT

Purpose: The aim of this work is to present the use of composite materials in the construction of freight cars. Particular attention was paid to the use of these materials in the construction of a freight wagon door. It is dangerous when mechanical damage is made to wall panels of a wagon during transport. Improperly distributed transported material can exceed the allowable stress level and thereby damage the lining of the wagon. One possible solution to this problem is replacing steel plates with composite panels which have better mechanical properties and do not cause an increase of the nominal weight of a freight wagon.
Design/methodology/approach: Experimental studies included: develop a research methodology of experimental tests of deformation of the wall door of a freight wagon. using strain gauge, placing strain gauges at key points, performed single-layer and double layer laminate panels with steel plates.
Findings: Composite materials made of 5 mm steel plate and a multilayer laminated panels can be used in the construction of freight cars.
Research limitations/implications: An expanded scope of the studies would include an analysis and synthesis of composite panels of various thicknesses, depending on the degree of damage to the hull of a freight wagon.
Practical implications: Composite panels can be applied in the repair and construction of freight wagon shells. The obtained result shows the possibility of reducing the weight of the whole railway carriage and the price of a wagon repair, eliminating the need to completely remove the shell.
Originality/value: Innovative use of composite panels in the repair and construction of structural elements of freight wagons, is new to the Polish scale. Initially DB Schenker Poland, is development of interest in further research and implementation of new technology.
Keywords: Composites; Mechanical properties; Computer assistance in the engineering tasks and scientific research; Numerical techniques; Engineering design; Physical distribution and logistics management

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1. Introduction

The article describes the scope, methodology and results of studies on the use of innovative materials for repair and construction of assemblies and subassemblies freight wagons. The scope of research and testing was limited to the modification of the door wagon. This was due to the specific requirements of the strength of the object. The standard number ORE B17/Rp 17 provides specialized in a particular case, the test strength door wagon, the pressure load. The test stand has been design and built according to the standard guidelines. The dimensions the test stand have been closely matched to the dimensions of the wall railway wagon: Length of wagon over buffers 14,040 mm

- Chassis length - 12,800 mm,
- Maximum width of the wagon - 3,040 mm,
- The length of the loading boxes - 12,784 mm,
- Width of cargo boxes - 2,792 mm,
- Torsional pivots wheelbase - 8,500 mm,
- Loading area floor - 36 m^2,
- Cargo volume - 73 m^3,
- The height of the rail car - 3,235 mm,
- The distance from the top floor of the railhead - 1,196 mm,
- Curb weight of the wagon - 20,500 kg ± 2% [3,4,10].

The study was carried out at the Department of Railway Rolling Stock Repair Industry DB Schenker in Rybnik-Kochłowice. Two complete walls of a freight wagon were used in this study. The study describes in detail the admission of industry standard ORE B17/Rp 17. It is a set of guidelines for static testing, which describes in detail the proper research methodology. The standards set out the basic research requirements, such as:

- A strength test of the side walls to lateral forces, by a load placed horizontally in the transverse direction (expanding type) on 4 central pillars of the two side walls, by 100 kN force, applied at the height of 1.5 m above the floor of the wagon (Fig. 1), and the strength of a body-side rail on impact, by a horizontal load in the transverse direction (expanding type) upper body-side rail in the middle of both side walls of the force 25kN and vertical force of 40 kN.

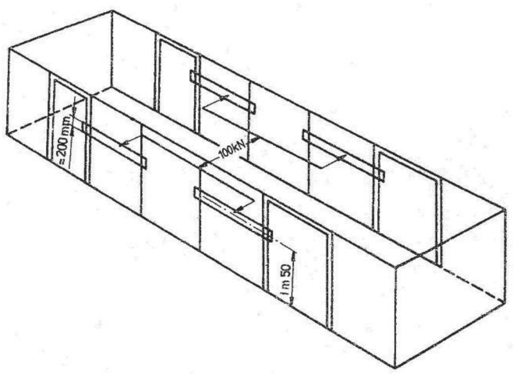

Fig. 1. The strength test of the side walls of the wagon [3]

- Checking the strength of the door with respect to a load of cargo, with a load of 20kN horizontal thrust, directed toward the outside of the wagon, applied at a height of 1m above the floor in the axis of the door opening, and the body-side load rail level in the transverse direction (expanding type), inside the door.
- Unloading the wagon using side tipper. Test are made during unloading the cargo, stress registration takes place at key points of the wagon body, (mainly in the sidewall and chassis) The measurement cycle includes the launch of the tipper of the wagon until the return to the starting position. test includes double strength 25 kN load on of the wagon [3,4,5,6,7].

2. The feature based-method

The feature-based method has been implemented in the Gliwice center for several years. Attempts were initially made to implement this method in the manufacturing process as defining elements of machines in the manufacturing process of division operations and machining operations. Then, there was an attempt to define the feature of rotating elements (such as shafts). Another attempt was made to define the functional feature, as objects acts in a motion simulation process.

The design process of composite panels had been s conducted in the use of feature-based method. The use of the method allows to combine the selection of characteristics for design, technology and supporting process, assuming the use of the existing CAx software. Application of this method is associated with mainly the mechanisms parameterization.

Parameterization may be subject to the entire design process from designing, manufacturing (technology), the operation, including information concerning the material properties of base elements. Feature is defined as the conceptual elements of both graphic and non-graphic, which can be described, analyzed and calculated, having the form and function, containing a set of relationships in the transformation of input, output and feedback that occur between them.

With regard to the design process of composite materials, a simple feature is a material which acts as a component (phase) of a single layer of fibrous composite. Only the minimum of two or more features create a material object with a higher stage of complexity, a complex feature. The Fig. 2 shows the following feature and systematize the knowledge on the use of feature-based method [4,5,6,7].

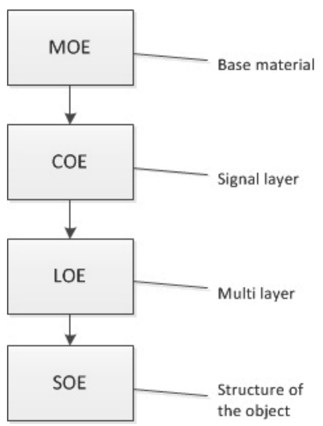

Fig. 2. The hierarchical structure of the feature

The basis for the formalization of a composite structure is the method of multiscale and multilevel modeling. A hierarchical structure for multiscale modeling,is shown in Fig. 3 which presents various phases of the development of the different values of a composite volume.

On the quantum scale, distinguishing engineering materials manufacturing technology, the basic object of this type is a subset of Technological Feature (TOE), which, in respect of materials, Material Technological Feature (MTOE), is a simple feature. Nano-scale represents the material feature. Material feature is a special case of feature information, which is a set containing information on the property and material properties of material engineering. MOE figure as a part of the database is shown in Fig. 5.

Identifying the material as a feature set, it was found that there exists a subset of the set of elements that are components of composite materials.

The highest degree of complexity of the feature is the structural feature. This is the submission of several types of feature, being an element, which is a part of the assembly or subassembly. The SOE consists of (Fig. 4):

- laminate feature - showing the character of the composite layer,
- geometric feature - showing the geometric form of the element,
- structural feature - showing the structure of the element,
- functional feature - defining the function of the element,
- technological feature - showing the manufacturing technology of the composite element. [2,4-7,9-15].

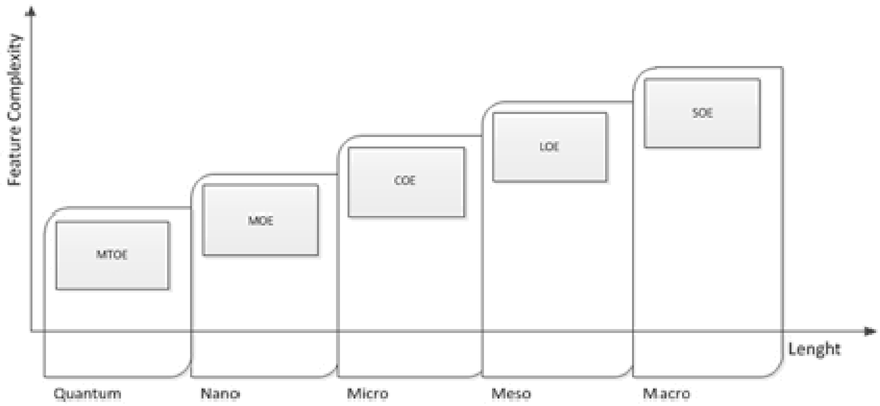

Fig. 3. Multiscale modeling of fibrous composite materials

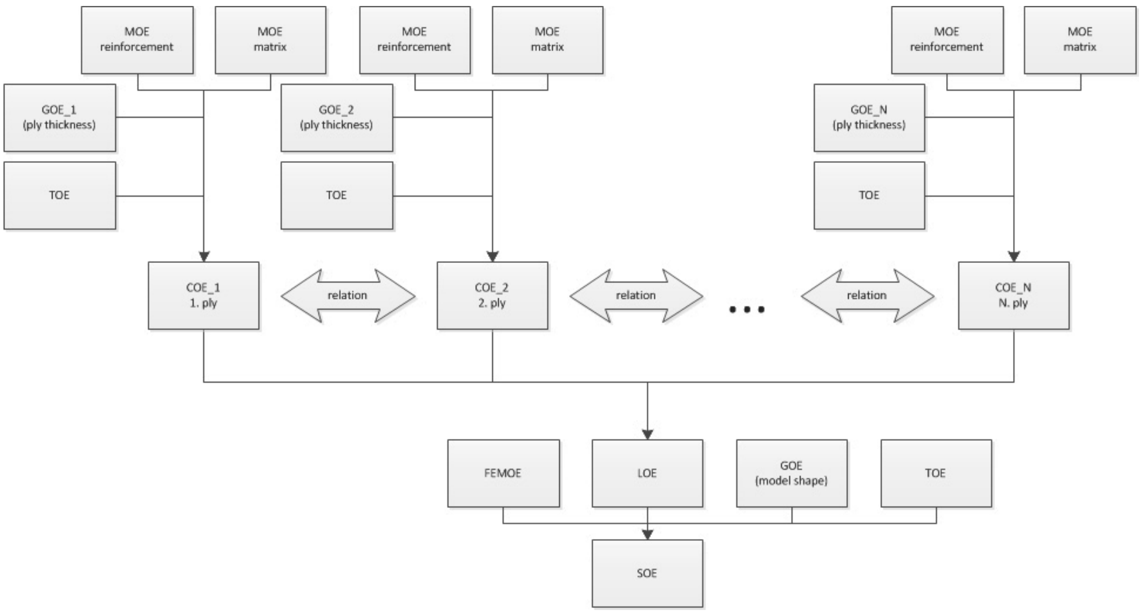

Fig. 4. The structure of the feature-based method

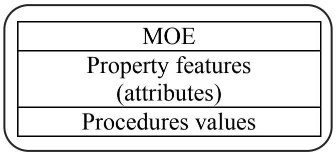

Fig. 5. Material feature

3. The testing station

In the design process of the testing station a 408Wb wagon model was used (Figs. 6 and 7), on which the final phase of the research was conducted. The purpose of this stage was to make such a station as would not create Operating Noise in the results, thus, the structure could not stiffen the wall more than is the case in a freight wagon. With this in mind, the station was combined with the wall in such a way as to accurately reproduce the conditions of its attachment to the rest of the freight wagon [3,4,10].

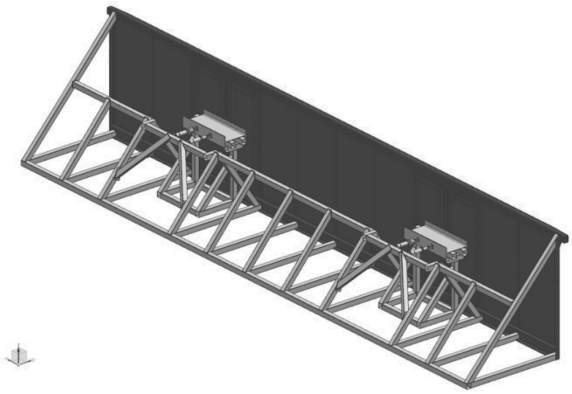

Fig. 6. The strength test of the side walls of the wagon

The station was built and placed in the hall of a repair facility.

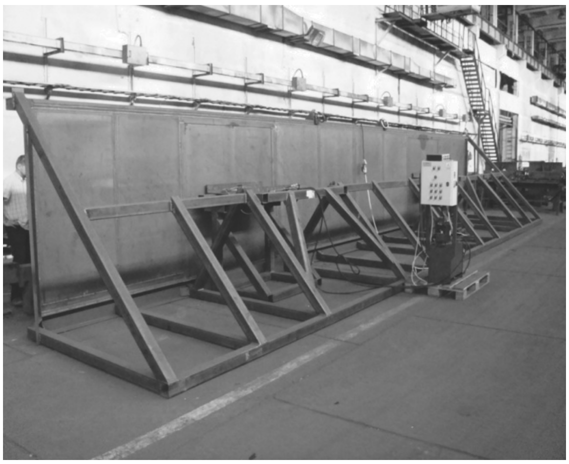

Fig. 7. The station ready for testing

The system used for setting the force in the construction company was made by BRYDEX-B. It consists of a hydraulic power supply UHBJ-40 / 1,1,1 / 2.2, six hydraulic cylinders BR ø50/ø36x100 CHT, a control box, and hydraulic pipes. A scheme of the hydraulic system, in the form of a diagram, is shown in Fig. 8.

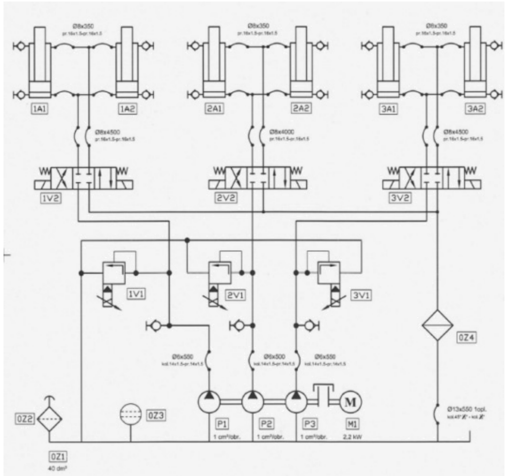

Fig. 8. The corresponding circuit hydraulic scheme

All components of the hydraulic system, with the exception of the pump placed inside the tank and immersed in oil, were placed outside the tank. The electric motor pump was mounted vertically on the outside of the tank and connected to the pump with a coupling. The system is equipped with three safety valves that protect against excessive pressure. In the system there are three valves which control the operation of actuators. Each of the valves controls two actuators connected to the series. Other elements a system of filters to ensure proper cleanliness of the oil, and an oil level indicator.

4. Experimental studies

The general experimental research was divided into three parts, to show the order in which tests were performed, and to better organize the results.

1. standard door mounted in the cars,
2. the doors single-layer laminate plate,
3. the door with mounting holes for rivet nuts,
4. the door reinforced with two-layer composite plate, combined with rivets nuts,
5. the door of a two-layer laminate plate and the additional rivet mounting holes.

Each measurement consisted of 10 round, by increasing the strength of the hydraulic system with gradually increased power, up to the pressure of 20 kN, required by the standard. The value of the pressure was kept constant for a few seconds, to generate graphs in catmanEasy. The process was repeated for an established number of passes. From the resulting pool of waveforms, three series of measurements were selected for each study, those burdened with the smallest errors, and then each of these series was divided into two groups: strain and stress.

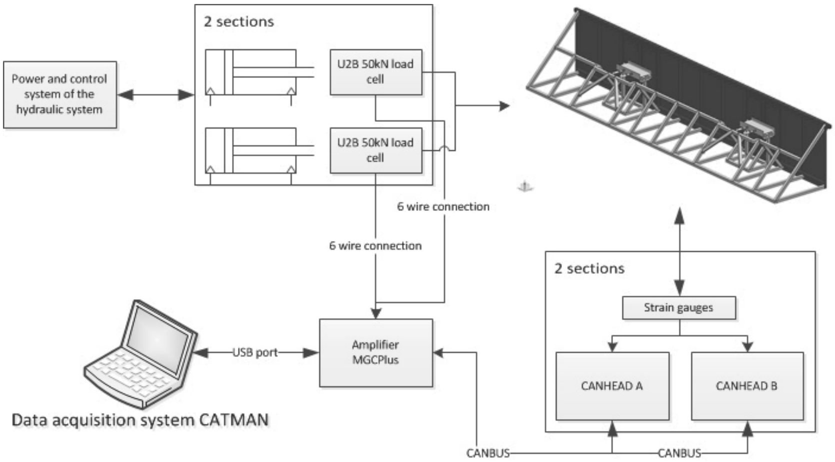

Fig. 9. The measuring circuit

The object of research is the wall of a wagon, The test arrangement are two hydraulic cylinders with U2B HBM load cell 50 kN. The actuators are controlled with the use of a hydraulic system to targetloads. On the outer side of the door there is a set of strain measurement gauges combined with wires connected to two CANHEAD amplifiers. Both force transducers and amplifiers are connected to a CANHEAD MGCplus amplifier, which in turn is connected to a PC via a USB cable (Fig. 9) [1,4,5,6].

In the study four laminated plates were used, made of composite fiberglass and polyester resin. Plate sizes were chosen according to the technical documentation of freight car doors: one single-layer plate with the dimensions of 1810 mm x 900 mm, one single-layer plate with the dimensions of 1810 mm x 870 mm, one dual-layer plate the dimensions of 1810 mm x 900 mm, and one dual-layer plate with dimensions of 1810 mm x 870 mm. In the production of all the plates glass fabric was used, with a density of 450 g/m2, and polyester resin Polimal AWTP 1094-1 with the Luperox K-1 hardener. The laminated panels were made in a workshop adapted and specially designed and built for the manufacture of a laminated manufacturing stand (Fig. 10) [2,4-15].

Fig. 10. The manufacturing stand for the manufacture of composite panels

For the installation of laminate plates steel rivet nuts were used, with internal thread M8, They were clamped in a steel plate and the supporting structure in the profiles of the door. The use of rivet nuts was found necessary to secure a lasting connection, without deteriorating the stability of the device, and for the purpose of quick installation and removal of additional items (Fig. 11).

Fig. 11. Rivet nuts

The study included three options of configuration of the fixing points of the plate-to-door composite of a freight wagon. The first variant takes into account the distribution of rivet nuts evenly over the entire surface of the panel door of a freight wagon. 14 points were used, mounted on a single leaf door (Fig. 12).

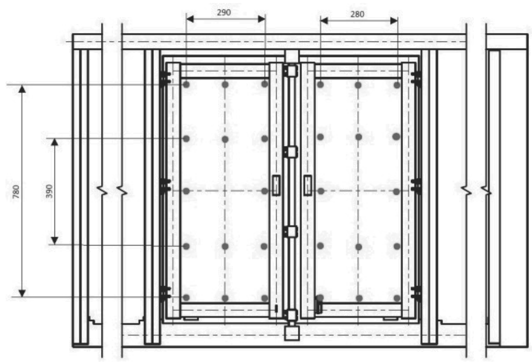

Fig. 12. The first variant

In the second option a total of 20 rivet nuts was distributed, of which 14 were located in one wing of the door, as in the first case. The other six were placed on the other wing in such a way that, from the outside of the door, all the rivet nuts were hidden steel profiles welded to steel plates (Fig. 13). This provided additional protection against damage and weather conditions.

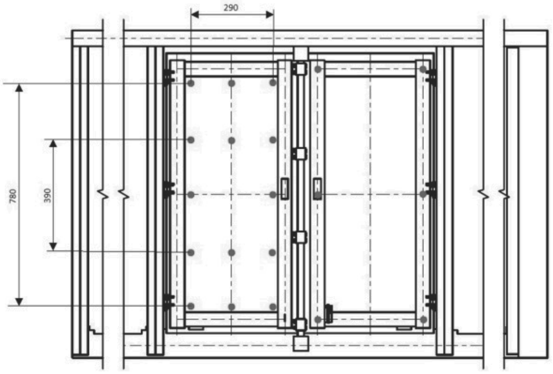

Fig. 13. The second variant

In the third variant The distribution of rivet nuts was not changed for one door. Four points of attachment were added to the right wing door (Fig. 14). As in the previous case they were hidden under profiles such as the mounting scheme shown in Fig. 13. Impact studies of additional holes in the distribution of increased stresses in the door were repeated. Ultimately, such a mounting scheme will be used in observational studies, as seen driving of a freight wagon, operated normally, which are in progress.

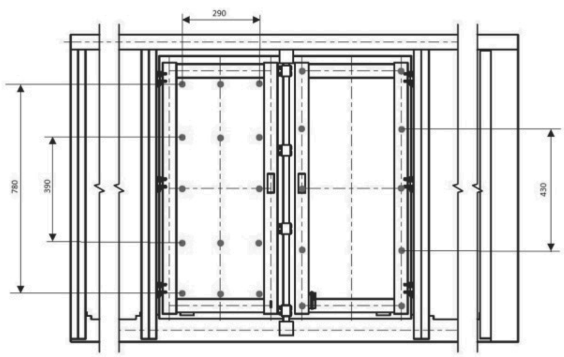

Fig. 14. The third variant

Based on the previously conducted analysis of the strength of a freight wagon, with numerical methods (the finite element method, computer-assisted), freight wagon door areas were established in which there were major differences in stress and strain. The strain gauges were placed at key points, according to the main direction in which the observed maximum values of strain and stress (Fig. 15).

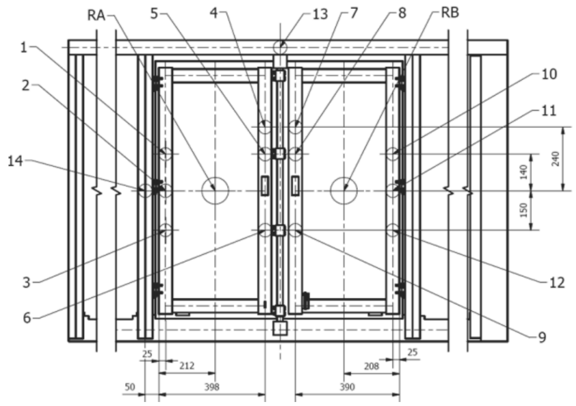

Fig. 15. The distribution and numbering of strain gauges

5. The results

The results of all measurements are summarized in Table 1. Strain gauges which recorded the greatest change of strain were highlighted on the graph (Fig. 16).

Table 1.
The summary of average values of strain

No Strain Gauge	Test 1. average value [μm/m]	Test 2. average value [μm/m]	Test 3. average value [μm/m]	Test 4. average value [μm/m]	Test 5. average value [μm/m]
1 (10)	134.19	152.05	108.77	103.86	103.86
2 (11)	204.95	215.77	169.88	161.70	161.70
3 (12)	106.42	116.44	112.90	116.25	116.25
4 (8)	178.54	184.20	178.53	169.62	169.62
5 (9)	401.09	424.21	377.06	352.98	352.98
6 (13)	355.09	378.35	299.92	289.79	289.79
7 (20)	217.90	243.21	134.90	128.31	128.99
8 (21)	461.34	485.74	479.98	463.87	468.43
9 (25)	289.37	299.85	495.23	477.04	483.85
10 (22)	178.94	184.91	164.77	157.03	157.61
11 (23)	179.59	179.03	206.23	189.59	191.59
12 (24)	118.67	125.93	183.64	176.40	175.70
13 (2)	-132.71	-150.63	-192.26	-183.44	-183.44
14 (27)	95.05	111.02	120.42	116.53	116.53
A1	359.32	271.52	665.62	675.90	675.90
A2	1051.43-	1064.39	1076.37	1053.31	1057.31
A3	539.54	559.95	563.47	547.39	547.39
B1	192.81	184.61	404.91	284.69	289.79
B2	476.68	530.56	599.99	488.72	503.21
B3	-126.02	-136.39	451.72	397.87	411.87

The comparative analysis is divided into five stages. The first step was to compare the values of stress and strain measurements 1 and 2. A comparison of the results of measurement 1 and measurement 2 was started by analysing the stress and strain of individual strain gauges in both measurements. Against the background of all measurement points we can distinguish strain gauges no. 9, 13, 25, and rosette A1. The maximum values of stress and strain of those strain gauges are on average two times larger than of other strain gauges. In addition, no. 2 and the strain gauge rosette B3 gave a negative value of strain and stress. It is very important that in these places the structure is compressed, and not, as in all other cases, expanded. In addition, measurement 2 for the measurement 1 is characterized by another important aspect. In almost all cases the values of stress and strain for measurement 2 are larger than for measurement 1. Importantly, measurement 2 was performed with an additional single layer laminate, however, fastened by rivet nut, measurement 1 was performed only on a steel plate. The only exception to this rule are the stress and strain rosettes B1, where the values are reduced when measurements of 2. The use of a single layer laminate, with the use of rivet nuts, does not improve the strength properties of the structure of a wall door of a freight wagon. In this situation the use of laminated plates with more than one layer and the development of a new distribution scheme of fewer rivet nuts may be justified.

The second stage involved the comparison of measurement 1 and measurement 3. As mentioned earlier, measurement 1 was performed only on the steel plate. Measurement 3 was made on a steel plate with holes drilled for rivet nuts, and arranged according to a new scheme developed on the basis of the conclusions from the previous measurement. Due to the change of strain gauges connected to the amplifier, strain gauges no. 2, 9, 13, and 25 of measurement A, in turn correspond to strain gauges no. 13, 5, 6, and 9 of measurement C. The most significant are the results of the strain measurement in a rosette. Strain rosettes B1 in measurement A was 192.81 µm/m measurement C was 404.91 µm/m. This comparison can be summarized with the conclusion that a mounting plate with rivet nuts causes a weakening of the structure, degrading its mechanical properties. The greater the number of rivet nuts, the greater the discontinuity in the structure of the wall door of a freight wagon, which ultimately leads to a deterioration of the mechanical properties of the whole structure.

The third stage of the comparative analysis of the results from measurements 1 and 4 was performed with the use of a double layer of laminate and an improved deployment scheme of rivet nuts - identical to measurement 3. The values of stress and strain for rosettes A and B are greater when measured with respect to measurement 4 and measurement 1. In the case of measuring strain gauge no. 2 (measurement 1) the absolute value of strain and stress increased, but the area remained on the structure compressed. For the strain gauge measuring points 9 and 13 (measurement 1) strain values decreased by about 50-60 µm/m and the stress by about 10 MPa. In short, in this measurement the negative effects of weakening of the structure through the use of rivet nuts have not been completely eliminated through the use of double layer laminate.

The fourth stage of the analysis compared measurements 1 and 5. Measurement E was made with the same measurement conditions as measurement 4. The only difference was the addition of four rivet nuts in the right wing wall door of the freight wagon. Was used to compare the same set of strain gauges as in the previous stage. The additional four rivet strength properties caused a decrease of stress by about 10 MPa.

The last step involved comparing measurements 3, 4, and 5. The values of stress and strain in measurement of 4 is smaller than measurements 3 and 5. For example, the average stress value in measurement 3 of rosette B is 247.61 MPa, in measurement 4 it is 200.84 MPa, and in measurement 5 it is 207.9 MPa. These results clearly indicate that fitting laminated plates with rivet nuts has a negative effect on the strength properties of the structure, in direct proportion to the number of used rivet nuts. At the same time the study showed that the distribution scheme of the rivet nuts, the use of double layer laminate causes levelling of this effect, and even a small improvement in the strength properties of the whole structure. The use of double layer laminate, attached to the steel plate through rivets arranged according to the developed scheme, does not improve the strength properties of the whole structure but only worsens them. It is necessary to use laminated panels with a greater number of layers. This proposal highlights the best comparison of mean values strain rosette B1 (Figure 16). In addition, Figure 17 shows the average values of strain rosette B of measurements 3, 4, and 5 .

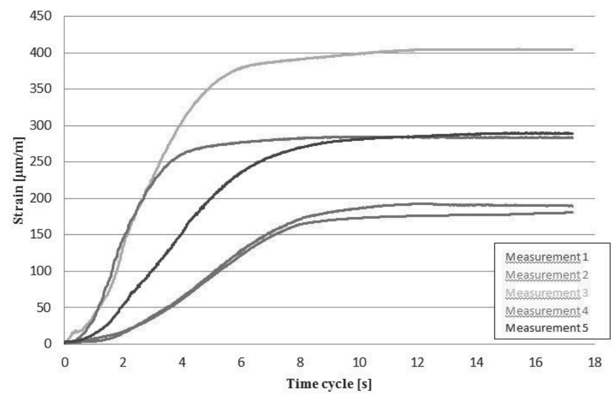

Fig. 16. Comparison of results of deformation measurements of 1-5, rosette B1

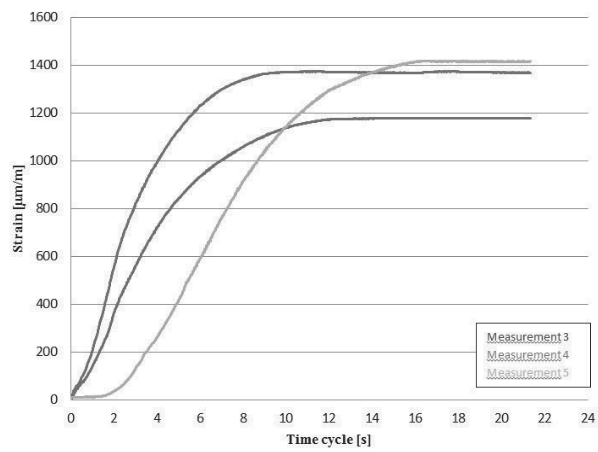

Fig. 17. Comparison of results of deformation measurements of 3-5, rosette B

6. Conclusions

Experimental studies described in this paper demonstrate the applicability of composite materials based on fiberglass panels in the construction of freight cars. The study was conducted on two pairs of a door of a wagon with two types of laminate plates and with different distributions of rivet nuts. The values of stress and strain generated during the construction of a load wall door of a freight wagon depend on the number of used rivet nuts and the structure of the composite material. The use of rivet nuts caused the deterioration of mechanical properties of the wall structure of the wagon. The optimal solution would be to use the 20 rivet nuts arranged according to the diagram shown in Figure 14 - the right wing. The use of two-layer laminated plates causes the levelling of the negative impact of rivet nuts on the strength properties of the structure, but only in places on steel profiles. Based on the survey and the above conclusions it can be safely assumed that the objectives of the work have been achieved. Composite materials made of 5 mm steel plate and multilayer laminated plates can be used in the construction of freight cars.

Acknowledgements

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