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Overview of joining methods of the layered composite with steel

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ABSTRACT

Purpose: The aim of this study was to explore how to combine laminate panels with a steel plate. The resulting sample composite panels were assembled with steel plate using two types of joints: with rivets and a rivet nuts. The analysis was carried out using resistance strain gauges. The results will be applied in the application of composite panels in the renovation of freight wagons.
Design/methodology/approach: Composite panels were produced using the contact method. A series of tests was carried out using a resistive strain gauge. Strain gauges were stuck in the form of a rectangular rosette. In addition, will be performed value measurement of application force and deformation at characteristic points.
Findings: It was found that the most significant impact on the ultimate strength of the composite fiber-steel has a diameter of drilled holes in the panels. The use of blind rivets and rivet nuts does not significantly change the mechanical properties combine complex components. The use of blind rivets creates artwork permanently solidified, while the use of rivet nuts allow the exchange of used composite panels, in the case of damage.
Research limitations/implications: Further research will include the use of other composite materials to cover the steel plate. There are also plans to perform research using CAx software in order to define the initial structure of the composite.
Practical implications: The article presents a number of basic research leading to the proposed methods joining composite and steel plate. A number of research, leading to information about the possibilities of use of the above composite materials in the process of repairing of freight wagons
Originality/value: These studies are very important for the application of composite materials in areas such as automotive, ship building and aviation.
Keywords: Composites; Fatigue; Mechanical properties; Engineering design; Technological design

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1. Introduction

The main objective of the research is to develop an innovative method of construction and renovation of the loading of freight wagons using the latest technologies and the development of procedures for repair of freight cars for the transport of bulk materials, particularly coal [1-3, 7-9].

As one of the stages of research attempted to examine ways of combining composites elements (fiber composites, layered) with steel parts. Considered joining methods using blind rivets, blind rivet nuts and bolts. Currently, the load space of the wagon is made primarily of steel profiles and steel sheets, joined together in welding technology. Repairs of wagons are carried out by cutting the damaged assemblies and components, and then welding the new ones. Therefore the desirability of research in the field of fastening technology which allows to install composites with the smallest possible number of required changes in the existing structure of the wagon [4,5].

Blind rivets are high-performance connecting elements, serving to implement sustainable shaped connections. Blind rivet consists of a closed sleeve rivet mounted on the shaft (pin) rivet. After entering the rivet to the connected element a force pulling the stem to form a molded head and the stem is broken off in the specially provided place. Thus, the creation of a call shall be deemed terminated. Rivet Bush is the connecting element. It is deformed by the rivet mandrel and becomes a permanent part of the structure. The selection of the sleeve is made taking into account the expected mechanical, corrosion resistance requirements, system design elements, combined thickness of the material, temperature loads and external appearance.

The rivet mandrel is needed to deform the rivet sleeve. Selection of the rivet shank sleeve depends on the type and the processing capabilities and the required performance. In some special types of rivets, the rivet mandrel residual remaining after deposition of the connection, is used to increase the shear force transmitted through the rivet.

There are three parameters describing the rivets - the minimum shear load, minimum load and maximum tensile breaking load of the core. Minimum shear load is the load in the radial direction, which is able to move rivet before the actual fracture. Tensile load is a load in the axial direction, the rivet is able to move before the actual rupture. Maximum breaking load of the core is a burden that must be applied to break into the core during the riveting process. According to the standard EN ISO 15973: 2000 mechanical properties of blind rivets are shown in Table 1.

Table 1.
Mechanical properties of blind rivets

Nominal diameter	Shear load Min	Tensile load Min	Breaking load of core Max
mm	N	N	N
3.2	1100	1450	3500
4	1600	2200	5000
4.8	2200	3100	7000
6.4	3600	4900	10230

Rivet nuts unilaterally closed in present times constitute an indispensable element of assembly techniques (Fig. 1). The use of rivet nuts allows to make highly loaded threads in structures, among others:

- thin parts or parts with a low endurance,
- empty profiles or other elements, in which there is no both sides accessing,
- elements of the already deposited protective coating.

Rivet nuts can be installed using a variety of devices designed for the deposition, which allows the use of appropriate mount rivet nuts. On the market there are tools that use muscle power and tools pneumatically or hydraulically driven. Riveting nuts deposition process is divided into three stages. In the first stage of blind rivet nut should be screwed into the tool shank. In the second stage, the nut should be introduced into the hole in the element and through the travel of the deposited. During this process is being created a molded head nut. The last third step is to unscrew the threaded shank of tool.

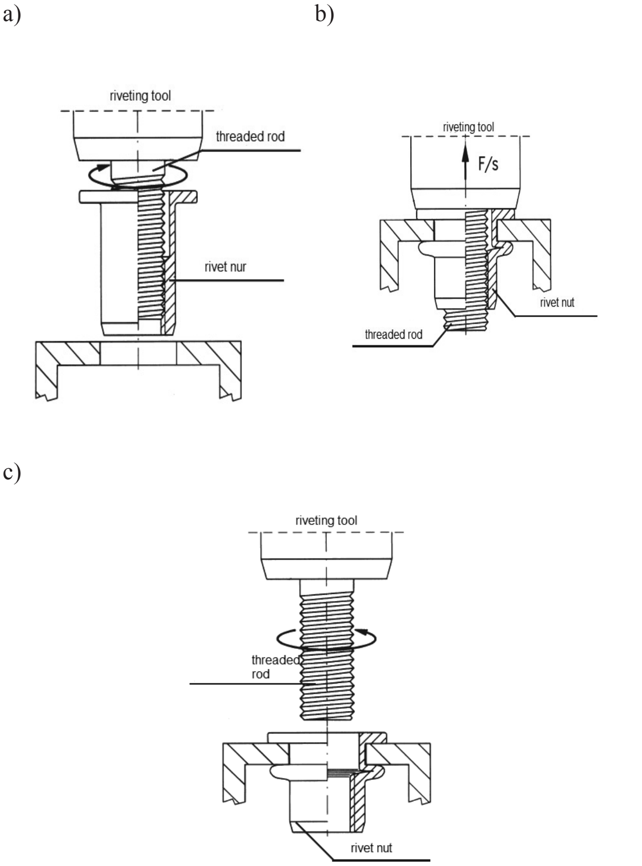


Fig. 1. Rivet nut mounting procedure, a) placement of the rivet nut, together with the tip of riveting tool, into drilled hole, b) clamping flange of rivet nut in the hole, c) unscrewing the tip of riveting tool

One of the mechanical parameters describing the rivet nuts is a maximum tightening torque of the screws. Manufacturer of rivet nuts has appointed maximum torque, as the lowest value of torque at which the nut has been damaged. A significant limitation of mounting rivet nuts is the maximum tightening torque of mounting screws. Exceeding the value of torque (Table 2), causing permanent deformation of the flange.

Table 2.
Mechanical properties of rivet nuts

Thread Size	Maximum torque	Maximum axial tensile force
	[Nm]	[N]
M4	3	2600
M5	4	4300
M6	6	6700
M8	18	11000

As a result, causing the rotation of rivet nut and loss of assembly property at the point of mounting. The second parameter describing the rivet nuts is a mechanical axial tensile force determined by the rules in accordance with DIN 7337. The data provided by the manufacturer shows the lowest value uniaxial tensile stress at which the cap has been damaged. As the damage was adopted strip the threads or break the head of the molded nut.

2. The methodology of experimental studies

In the experimental studies had been used resistive strain gauges placed on the top layer of the composite. Changes in voltage in resistance strain gauges are very small for their proper reading and analysis is necessary to use equipment with high accuracy. In the described measurements were used test equipment Hottinger Baldwin Messtechnik. Measuring circuit used for deformation measuring, using the position of static delamination for testing are shown in Figure 2. Figure 3 shows the measuring circuit used for measuring on the position for fatigue tests [1,2,4,5,9].

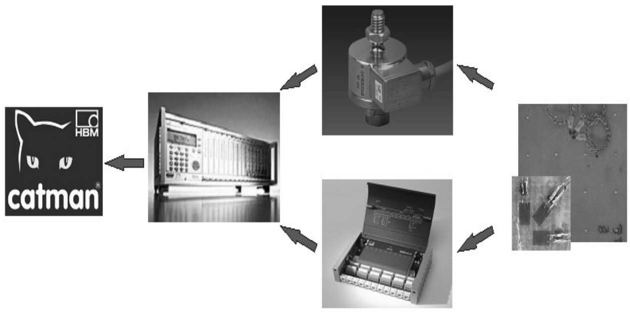


Fig. 2. Measuring circuit for delamination test

Fig. 3. Measuring circuit for fatigue test

Rosette had been made from three strain gauges codenamed TEN-TF3/120. Utilized strain gauges are characterized by 120 Ω resistance and gauge factor 2.15. Strain gauge Rosette has been connected to Canhead amplifier. The signals from the amplifier Canhead and U2B force sensor, which measures contact force on the sample, has been send to the measurement amplifier MGCPlus. The acquisition of measurement data is performed on a PC, using software CATMAN. The load on the sample inflicted by a hydraulic cylinder. Described position is shown on Figure 4.

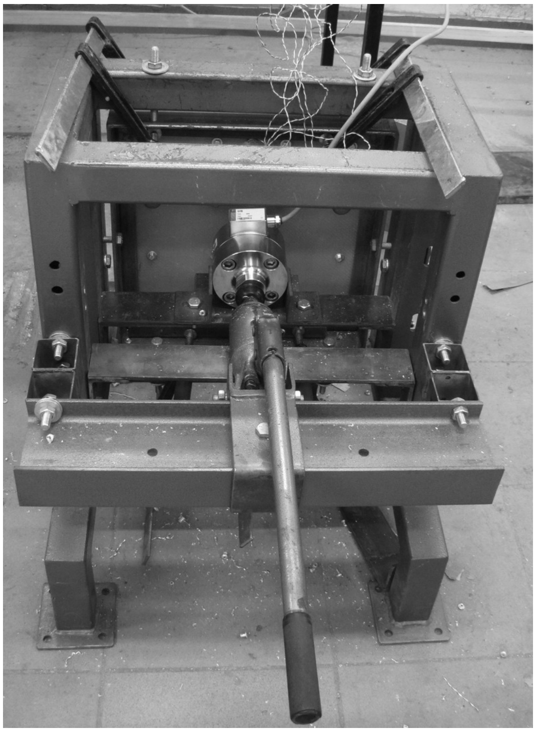


Fig. 4. Stand for testing of static delamination

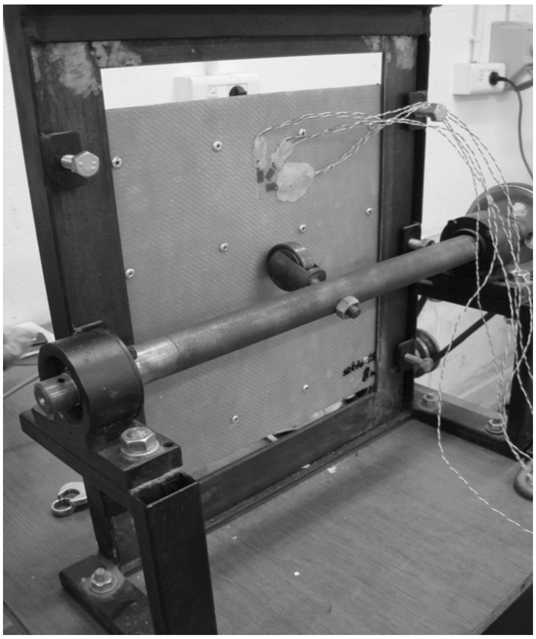


Fig. 5. Stand for fatigue test

Measuring circuit used for fatigue measuring was built according to the diagram at Figure 4. Measuring circuit starts from the sample, on which is mounted a rectangular strain gauge rosette. Rosette Strain gauge amplifier has been connected to Canhead. Signals from the Canhead amplifier and transducer WA 20L (displacement transducer), has been sent to the measurement amplifier MGCPlus.

The measurements were carried out on a test stand shown on Figure 5. The load was transferred to the sample through the eccentric shaft, which was driven by an electric motor. The motor speed was regulated through inverter.

In the Table 3 is shown list of examined samples.

To each sample is assigned identifier. On the pictorial illustration shows direction of the load and provides connection method of laminate with steel plate. The last column of the table contains the basic parameters of the laminates.

Notation used in the analysis of the measurements"

F - the theoretical load applied,

F_{rz}- actual load applied,

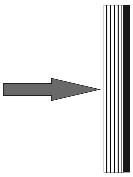
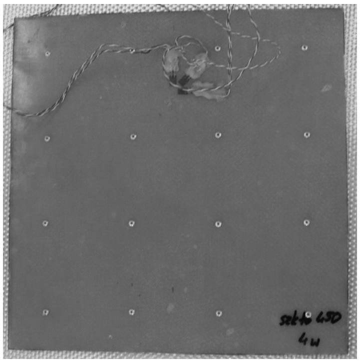
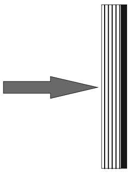
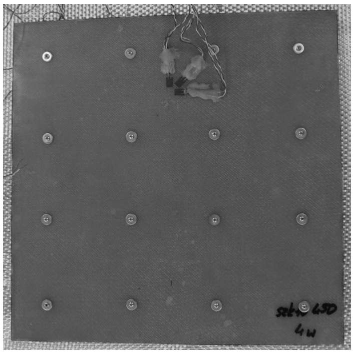
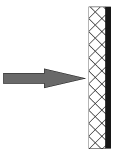
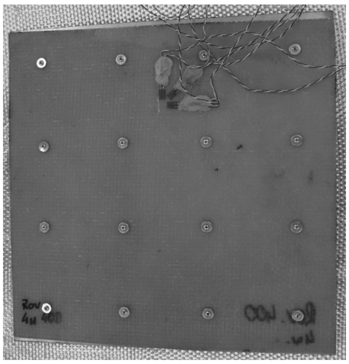
ε_{max}, ε_{min} - deformation maximum and minimum

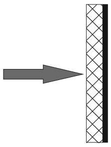
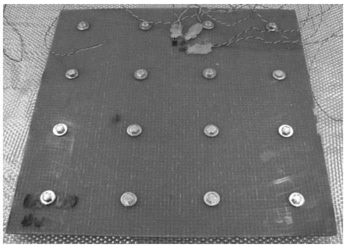
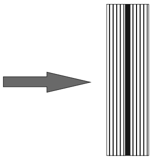
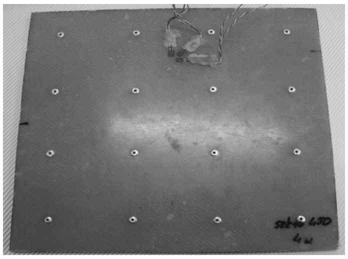
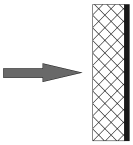
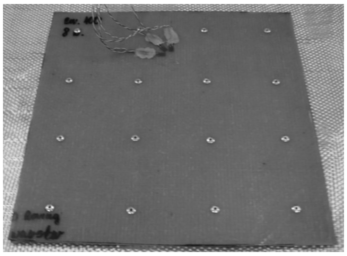
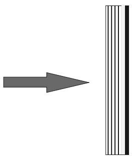
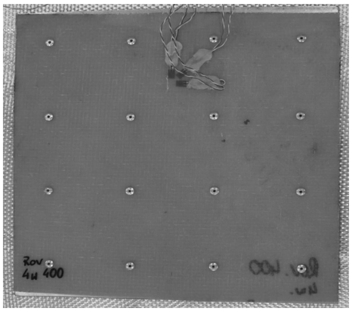
γ_{xy}- angle of shear strain,

ε_0, ε_{45}, ε_{90}- strain measured at 0°, 45°, 90° to the x axis,

α_g- deflection angle between the main and the direction of the x-axis.

Table 3.
The study plan

No	Sample determination	The direction of the load		The connection method	Parameters of laminate
1.	Pr5.			16 blind rivets with a diameter of 3 mm. Diameter of the hole 3.1mm.	Number of layers: 4 Mass: 515g Thickness: 2.24mm Reinforcement: S fiber glass, satin weave 450 g/m^2 Matrix: Epidian 6 Attention:
2.	Pr9.			16 rivet nuts i screw with a thread M3 Diameter of the hole 5.1mm.	Number of layers: 4 Mass: 515 g Thickness: 2.24 mm Reinforcement: S fiber glass, satin weave 450 g/m^2 Matrix: Epidian 6 Attention:
3.	Pr11.			16 blind rivets with a diameter 4.8 Diameter of the hole 5 mm.	Number of layers: 4 Mass: 370 g Thickness: 1.96 mm Reinforcement: S glass roving, plain weave 400 g/m^2 Matrix: Epidian 6 Attention:

No	Sample determination	The direction of the load		The connection method	Parameters of laminate
4.	Pr12.			16 rivet nuts i screw with a thread M3 Diameter of the hole 5.1mm.	Number of layers: 4 Mass: 370g Thickness: 1.96mm Reinforcement: S glass roving, plain weave 400g/m^2 Matrix: Epidian 6 Attention:
5.	Pr15.			16 blind rivets with a diameter of 4.8mm. Diameter of the hole 5.1 mm.	Number of layers: 2 x 4 Mass: 2 x 515g Thickness: 2 x 2.24mm Reinforcement: S fiber glass, satin weave450g/m^2 Matrix: Epidian 6 Attention:
6.	Pr16.			16 blind rivets with a diameter of 4.8mm. Diameter of the hole 5mm.	Number of layers: 8 Mass: 740g Thickness: 3.84mm Reinforcement: S glass roving, plain weave 400g/m^2 Matrix: Epidian 6 Attention:
7.	Pr20.			16 blind rivets with a diameter of 4.8mm. Diameter of the hole 5mm.	Number of layers: 8 Mass: 740g Thickness: 3.84mm Reinforcement: S glass roving, plain weave 400g/m^2 Matrix: Epidian 6 Attention: Steel plate is covered with a layer of anty-corrosion substance

3. The results of research

3.1. Delamination test

Measurements of the test cycle were carried out on three specific load values. This approach allows to check the strength of connections and influence made holes in the laminate. Due to the possibility of the bench composite panels been studied using the force loading of 0.33 kN and 0.66 kN and 1.0 kN. Measurements been recorded using three resistance strain gauges arranged in a rectangular rosette. Strain measurement was performed at three angles 0º, 45º, 90º. The recorded measurements are shown in Figures 7 to 13. The graphs show the deformation of individual resistance strain gauges, the strength and value of the average strain. All measurements has been performed as a function of time [7,8].

Legend for the designation of samples in the study plan is shown in Figure 6.

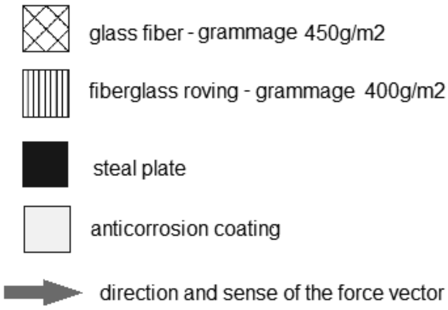


Fig. 6. Legend for the designation used in the study plan

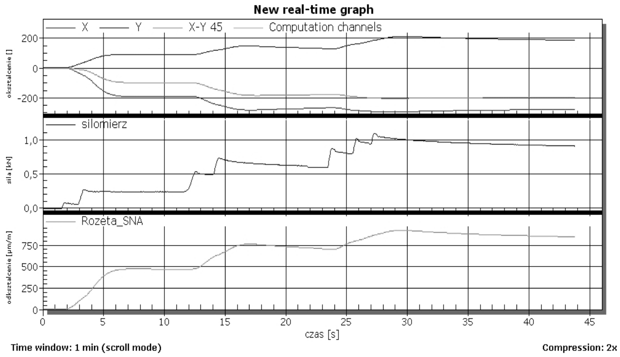


Fig. 7. Graph of strain PR5

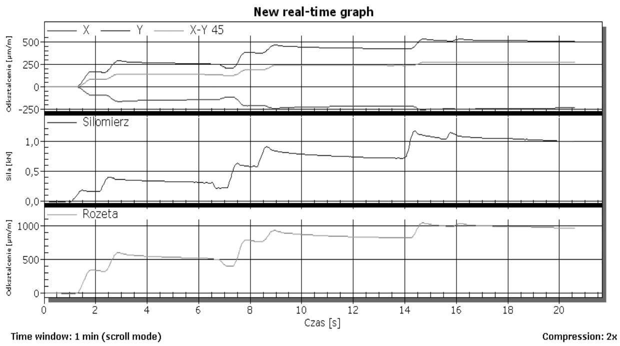


Fig. 8. Graph of strain PR9

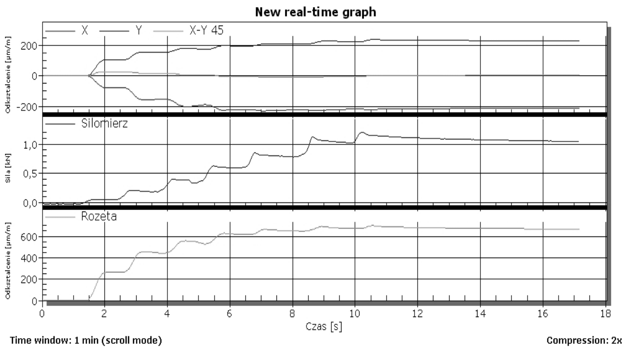


Fig. 9. Graph of strain PR11

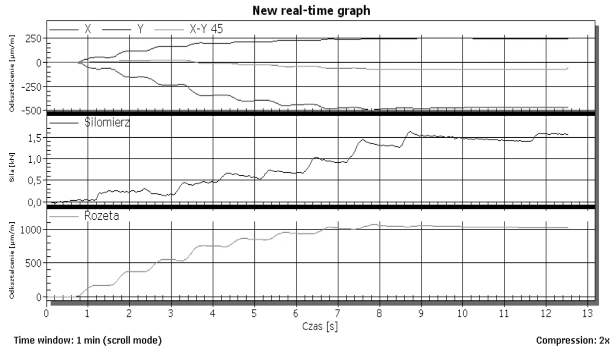


Fig. 10. Graph of strain PR12

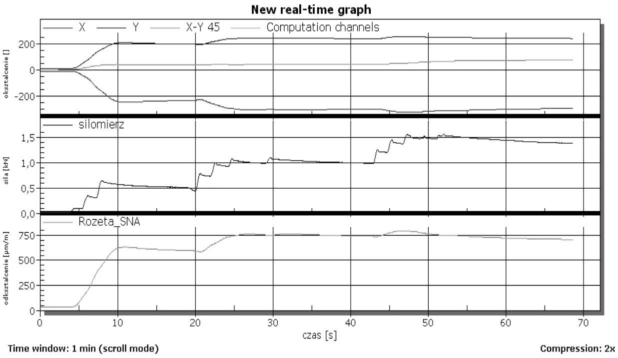


Fig. 11. Graph of strain PR15

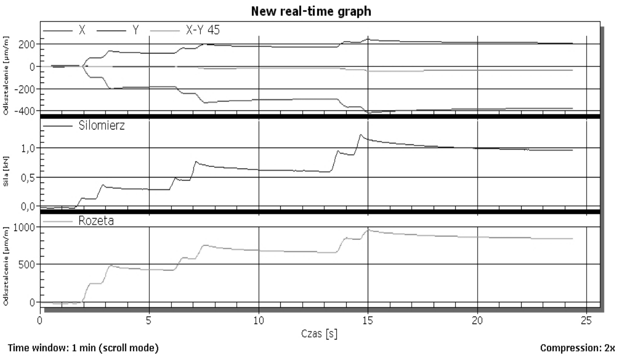


Fig. 12. Graph of strain PR16

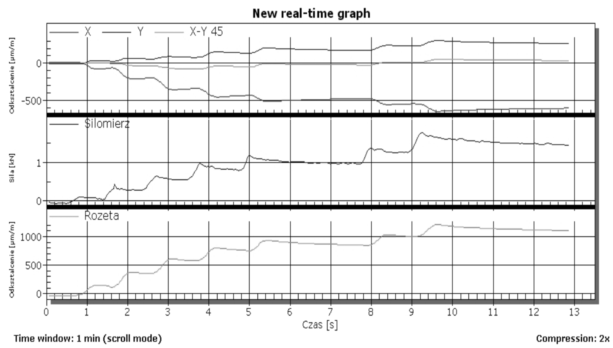


Fig. 13. Graph of strain PR19

Figures 7-13 represent the three graphs. The top graph shows the strain measured at the point of attachment strain gauge rosettes. Graphs has been labelled by:

- X - shows the measured strain in the strain gauge placed in the X-axis
- Y - shows the measured strain in the strain gauge placed in the Y axis
- X-Y-45 shows the measured strain in the strain gauge placed in an intermediate position at an angle of 45 degrees relative to the X and Y axis.

Middle graph shows the course of the contact force [kN].
The last graph shows the average value of the strain measured in strain gauge rosette

Average values of all the measurements has been entered in Table 4.

PR5 sample was made using rivets, and sample PR9 with threaded inserts. Both attempt has been made with a four-layer composite, reinforced with glass fiber fabric. The mounting holes were different in the two cases. On the sample PR9 has been made holes with a diameter of 5.1 mm, while in the sample PR5 3.1 mm. A notable advantage of rivet nuts in this case is the ability to quickly and easily replace the composite panel which would compensate the reduced strength.

From the results it is noted that the maximum deformation of the specimens PR11 and PR12 take similar values. This comparison confirms the assumption that the use of blind rivet nuts and bolts of the lower thread is more advantageous. Compared to the sample PR9 fiberglass reinforced with a weight 450 g/m^2 strain the value of the sample is smaller than the S glass roving, plain weave reinforced with a weight 400 g/m^2.

PR15 sample was made as symmetrical, it is evident a significant reduction in strain of the sample. Configuration of the connection is identical with applied in the samples PR5, PR9. The symmetrical arrangement of the laminate with the increased number of layers reduces the strain, improving rigidity.

Restricting the use of practical on freight wagons of the solution proposed in the sample PR15, it can be difficult assembling the panels on the outer side of the cargo space. Configuration of the proposed composite sample PR16 - associated with a slightly inferior mechanical properties, and allow proper installation on the real object.

Table 4.
Average results of the measurements

F	ε_0	ε_{90}	ε_{45}	F_{rz}	ε_{max}	εmin	α_g	γ_{xy}
[kN]	[μm/m]	[μm/m]	[μm/m]	[N]	[μm/m]	[μm/m]	[°]	[μm/m]
				PR5				
0.33	-189.534	91.087	-98.686	0.338	99.527	-197.974	-29.591	470.392
0.66	-280.894	147.882	-181.645	0.66	176.807	-309.819	-30.257	758.303
1	-292.817	212.294	-203.558	1	260.443	-340.965	-30.629	920.964
				PR9				
0.33	-148.09	262.592	137.559	0.33	277.704	-163.202	-26.263	535.715
0.66	-211.523	413.346	226.764	0.7	437.69	-235.867	-26.201	811.452
1	-237.009	504.611	274.278	1.003	530.268	-262.666	-26.328	971.953
				PR11				
0.33	-197.778	177.846	4.915	0.338	178.406	-198.339	-27.861	551.073
0.66	-219.688	195.319	-4.441	0.634	195.432	-219.801	-28.044	617.284
1	-211.519	229.351	5.052	1.046	229.351	-211.52	-28.282	667.687
				PR12				
0.33	-254.664	173.944	17.213	0.391	181.509	-262.23	-26.894	585.339
0.66	-360.601	205.659	-12.353	0.649	213.007	-367.949	-27.085	784.273
1	-452.416	231.902	-46.03	0.99	237.825	-458.339	-27.291	962.249
				PR15				
0.33	-134.052	9.995	-38.605	0.349	13.697	-137.753	-53.214	192.647
0.66	-282.334	21.325	-78.354	0.660	45.669	-206.678	-51.272	503.337
1	-310.456	50.546	-68.308	1.016	93.741	-353.650	-50.471	679.856
				PR16				
0.33	-160.247	115.68	-1.911	0.333	117.155	-161.722	-27.482	393.518
0.66	-314.112	187.253	-18.385	0.667	191.229	-318.089	-27.329	707.002
1	-384.777	216.843	-36.699	1.003	220.488	-388.422	-27.437	855.163
				PR19				
0.33	-238.579	95.470	15.400	0.370	116.721	-259.829	-25.555	414.120
0.66	-335.858	85.555	-1.837	0.647	118.950	-369.254	-25.184	508.806
1	-392.116	77.904	-8.568	1.015	120.869	-435.080	-24.908	556.493

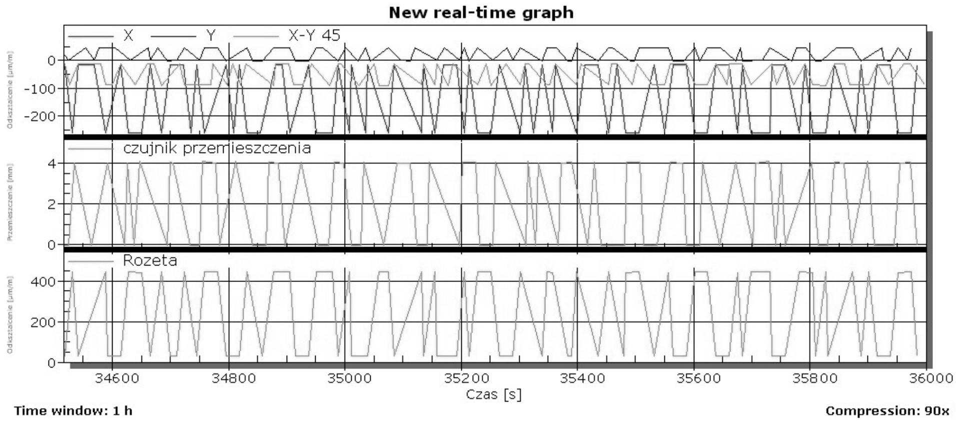


Fig. 14. Graph of measuring fatigue test sample PR20

Deformation of the of samples PR16 and PR20 takes a similar value. These results confirm the earlier assumption that the use of elastic deformation of the layer reduces the corrosion resistance of the sample. Another advantage is the protection of the contact laminate - steel, thus preventing the ingress of water between the layers.

3.2. Fatigue test

Sample PR20 is made of eight-layered glass fiber reinforced laminate with a weight 450 g/m^2. The laminate is combined with steel plate by using steel plate sixteen rivets 4.8 mm in diameter.

The sample was loaded at a frequency equal to 0.125 Hz. Sampling frequency in the Catman has been set to 50 Hz. On the basis of the graphs can be seen that the amplitude of strain of the sample during testing was increased by 2% rather strain been included in the range of elastic deformation. The frequency response of the load strain gauges was approximately 0.25 Hz, the measuring system registered a quarter of the load cycle. In order to improve the quality of the measurements should reduce the frequency reference load and reduce the number of collected results by reducing the sampling frequency.

Because of the level of complexity of fatigue testing the section, has been shown only just a sample of the study.

4. Conclusions

Influence of the method joining composite steel sheet does not affect the difference in the deformations. Large holes caused an average 56.9% increase in deformation (samples PR5 and PR9). Samples taken with S glass roving, plain weave (sample PR11 and PR12) were made with the same number of attachment points, the difference in deformations is 4.6%, and this may be considered as a measurement error. Of the samples taken with eight-layered composite configuration was most advantageous for the sample PR15-due to the symmetry of the distribution of layers with a steel core. The use of cover in the form of anti-corrosion coating slightly improved the mechanical properties of the composite eight-layer single-sided.

Acknowledgements

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