THE STRENGTH OF POLYMER MATERIALS'ADHESIVE JOINTS, APPLIED IN THE AUTOMOTIVE INDUSTRY

Wytrzymałość połączeń klejowych tworzyw polimerowych stosowanych w przemyśle motoryzacyjnym

Прочность клеевых соединений полимерных материалов применяемых в автомобильной промышленности

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A b s t r a c t: The article describes the shear strength and statistical analysis of adhesive joints of four polymers used in the automotive industry, i.e. polypropylene, polystyrene, polyamide and polyacetal. Adhesive joints were prepared using two types of epoxy adhesive: Epidian 57/IDA/100:50 and Epidian 6/TFF/100:27. Surfaces of bonded materials prior to the bonding process were prepared using sandpaper P120, and then to remove impurities formed after mechanical treatment, the surface of polymer materials was degreased with acetone. The adhesive joints after the curing process were subjected to a strength test on the Zwick/Roell 150 strength machine in accordance with the PN-EN 1465 standard. The STATISTICA program was used for statistical analysis of the results of the strength tests. Parameters of descriptive statistics were determined, normality of distribution was determined and statistical tests of strength parameters were carried out. It was noted, among other things, that the greatest shear strength was obtained by adhesive joints of HIPS 425N polystyrene bonded Epidian 6/IDA/100:50 epoxy adhesive. However, the smallest shear strength was characterized by the adhesive joints made of Tarnamid T-27 polyamide bonded with Epidian 6/TFF/100:27 adhesive, which amounted to about 30% of the highest strength value obtained.

K e y w o r d s : adhesive joints, strength, polymer materials

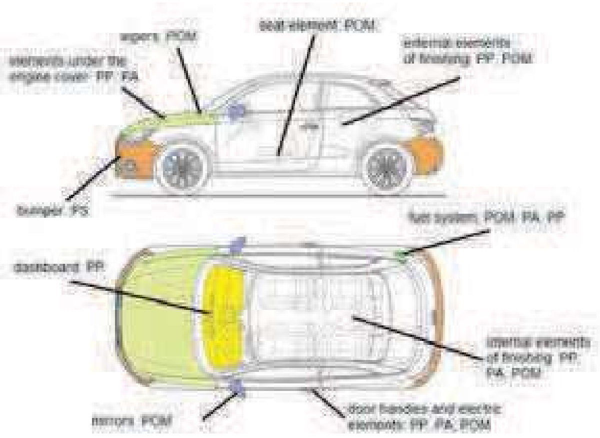
S t r e s z c z e n i e: W artykule opisano badanie wytrzymałości oraz analizę statystyczną wyników pomiarów wytrzymałości na ścinanie połączeń klejowych czterech polimerów stosowanych w przemyśle motoryzacyjnym, polipropylenu, polistyrenu, poliamidu oraz poliacetalu. Połączenia klejowe przygotowano za pomocą dwóch rodzajów klejów epoksydowych: Epidian 57/IDA/100:50 oraz Epidian 6/TFF/100:27. Powierzchnie łączonych materiałów przed procesem klejenia zostały przygotowane za pomocą papieru ściernego o gradacji P120, a następnie w celu usunięcia zanieczyszczeń powstałych po obróbce mechanicznej, powierzchnia tworzyw polimerowych została odtłuszczona acetonem. Połączenia klejowe po procesie utwardzenia poddano badaniom wytrzymałościowym na maszynie wytrzymałościowej Zwick/Roell 150, zgodnie z normą PN-EN 1465. Do analizy statystycznej rezultatów badań wytrzymałościowych, wykorzystano program STATISTICA. Wyznaczono parametry statystyki opisowej, określono normalność rozkładu oraz przeprowadzono testy statystyczne badanych parametrów wytrzymałościowych. Zauważono m.in., że największą wytrzymałość na ścinanie uzyskały połączenia klejowe polistyrenu HIPS 425N, wykonane klejem Epidian 6/IDA/100:50. Natomiast najmniejszą wytrzymałością charakteryzowały się połączenia klejowe wykonane z poliamidu Tarnamid T-27, klejone klejem Epidian 6/TFF/100: 27, która stanowi około 30% największej otrzymanej wartości wytrzymałości.

S ł o w a k l u c z o w e :połączenie klejowe, wytrzymałość, tworzywa polimerowe

Introduction

Since the beginning of its existence, the automotive industry has been recognized by the engineers as one of the main branches of the global industry due to the possibilities which may offered in respect of development of construction, technologies and materials. Willingness to obtain newer and better solutions in the field of construction and operation of car has induced a global race of the producers of vehicles. The increasing number of cars and a rise of the level of the ecological awareness was the reason for introduction of legal regulations aimed at the limitation of exhaust emission [1]. To adapt to the legal regulations, many new constructional and technological methods were introduced; they were intended to limit the mass of the vehicle and reduce the fuel consumption; to these ends, inter alia, light materials were used (aluminium alloys, composites and polymers). Reduction of the mass by 10% allows limiting the consumption of fuel by 5-7% [2].

Fig.1. Application of the selected polymers in a car [1. 3]
Rys. 1. Zastosowanie wybranych polimerów w samochodzie [1,3]



Polymers are the example of materials which have a wide application in car vehicles [2, 4, 5]. Fig. 1 shows the element of car which are manufactured with the application of various types of polymers, including those ones used in the studies, discussed in the present paper. Apart from the elements, presented in Fig. 1, there are many smaller or greater car parts, produced from other polymers such as PVC or ABS (acrylonitrile butadiene styrene) [2]. Polymer elements are often connected using gluing technology [6-8] because gluing allows, inter alia, joining different constructional elements with different physical properties [9]. Such necessity occurs during assembly of different car parts. Additionally, it is an effective method for connecting materials of such type due to aspect of joint tightness what, in the case of car, is very important [10].

Strength is one of the specific parameters of the adhesive joint. The value of adhesive joint is affected by many factors, classified as follows [6, 11]:

- Constructional – size of joint, dimensions and shape of joint, the way of its loading;
- Technological – preparation of surface of the elements to be joined, choice of adhesive, preparation of adhesive mass, conditions of performing and hardening of adhesive joint (time, temperature, humidity, stress, storage conditions;
- Material – surface structure, physical properties of the materials to be joined, state of upper layers;
- Operating – time of the connection work

When assessing the strength of adhesive joint, we consider, inter alia, the direction of external forces' effect, causing the stress in the joint. Hence, due to the greatest stress, the joined samples are subjected to the shear strength tests. To this end, the lapped connection is often applied.

The aim of the work was to examine the strength of adhesive joints of the selected polymer materials which have the application in the automotive industry. To perform the adhesive joints, two different glue combinations, based on epoxy resins, were used. The paper contains the run of the tests and description of the shear strength measurements of the performed adhesive joints and statistical analysis of the obtained values, using STATISTICA program [12 – 14].

Methodology

Description of the materials to be joined

To perform the adhesive joints, the samples of the following polymer materials were utilized:

- PP – polypropylene (Malen P),
- PS – polystyrene (Tarnamid T-27),
- PA – Polyamide (Tarnoform T-300 Nat),
- POM – Polyacetal (HOPS 425N).

The test samples were obtained as a result of injection of the tested materials and were characterized by unchangeable dimensions, being the mapping of the shape and size of the sockets of the applied injection form. Each polymer sample, as visible in Fig. 2, had the following dimensions: length – 100 ±1 mm, width – 10±0.5 mm and thickness – 4±0.2 mm.

The conditions for performance of adhesive joint

The preparation of the surface was conducted prior to the performance of the adhesive joints. To these ends, the sandpaper P120 was used; 20 circular motions were carried out, obtaining the unidirectional structure. Then, to remove the impurities formed after the mechanical treatment, the surface of the polymer materials was degreased with acetone [4].

Fig.2. Sample of polymers: a) polypropylene, b) polyamide c) polyacetal
Rys. 2. Próbki wykonane z tworzyw: a) polipropylenu, b) poliamidu, c) poliacetalu, d) polistyrenu

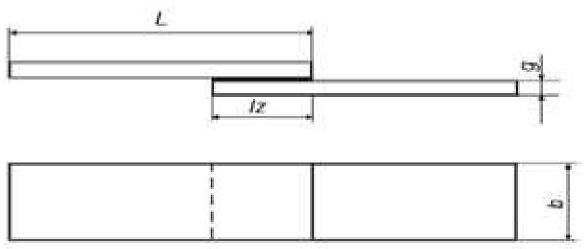
Tab. 1. Summary of the dimensions of adhesive joints
Tab. 1. Zestawienie wymiarów spoin klejowych

Polymer		Length of adhesive joint [mm]	Thickness of adhesive joint [mm]	Surface of bonded area [mm2]
PP	$\bar{X}$	18,76	0,12	187,73
	σ	1,63	0,05	16,35
PS	$\bar{X}$	18,29	0,23	182,82
	σ	1,78	0,22	17,79
PA	$\bar{X}$	17,40	0,41	173,81
	σ	1,34	0,14	13,36
POM	$\bar{X}$	15,42	0,12	154,00
	σ	0,59	0,15	5,82

$\bar{X}$ – mean value
σ – standard deviation

To perform the bonding process, 2 types of epoxy adhesives were used. The first glue was the composition of epoxy resin Epidian 6 and the hardener IDA, mixed in ratio 100:50 (Epidian 6/IDA/100:50). The mentioned type of adhesive was utilized when bonding the samples of propylene and polystyrene. The second composition included mixture of epoxy resin Epidian 6 and the hardener TFF, at ratio 100:27 (Epidian 6/TFF/100:27). The mentioned type of adhesive was used in joining polyamide and polyacetal.

Fig. 3. Scheme of a single overlap adhesive joint
Rys. 3. Schemat połączenia klejowego jednozakładkowego



Scheme of adhesive joint and strength tests

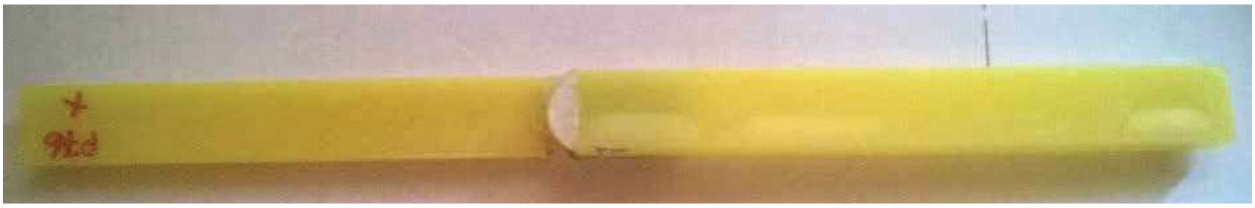
To perform the experimental tests, 48 samples made from 4 polymer materials were prepared; 24 adhesive joints were performed. The samples were divided into two groups, depending on the used adhesive. The real length of the overlaps is given in Tab. 1. The scheme of a single overlap adhesive joint is presented in Fig.3 and Fig.4 shows the example of adhesive joint of polyacetal.

The length of the adhesive joint is different only for polyacetal and is equal to 15.42 mm. In the case of the remaining materials, the discussed length of the joint is found on the level of 18 mm.

During the bonding process, the ambient temperature was equal to 22oC ±2oC and humidity 23%±2%. The performed joints were hardened in cold for 7 days under the same conditions as during the bonding process, under loading of ca. 10 N. After the mentioned period, the samples were subjected to destructive tests in Zwick/Roel Z 150 strength machine in accordance with the standard PN-EN 1465 [15].

The obtained results of the strength tests were subjected to statistical analysis, using STATISTICA program.

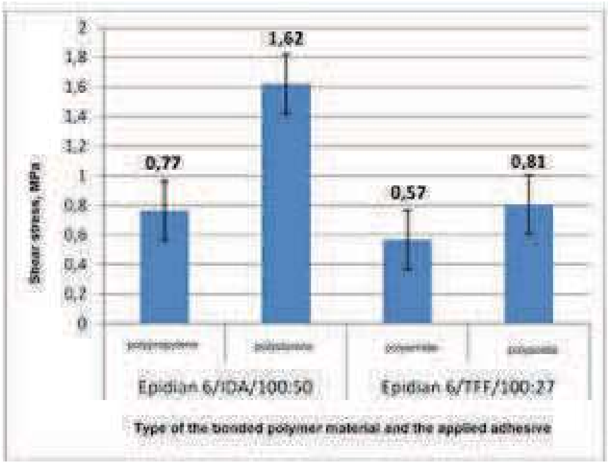
Fig. 4. The example of adhesive joint made of polyacetal HIPS 425N, using composition of adhesive Epidian 6/TFF/100:27
Rys. 4. Przykładowe połączenie klejowe wykonane z poliacetalu HIPS 425N przy zastosowaniu kompozycji klejowej Epidian 6/TFF/100:27



Tab. 2. Summary of the parameters of the strength of adhesive joints
Tab. 2. Zestawienie parametrów statystyki opisowej wytrzymałości połączeń klejowych

Polymer	Parameters of descriptive statistics									
	Number of samples	Mean	Median	Mode	Mode size	Range	Variance	Stand. dev.	Skewness	Kurtosis
PP	6	0,765	0,72	Multiple	1	0,5900	0,0382	0,1954	0,6990	-0,9237
PS	6	1,620	1,60	Multiple	1	0,9400	0,0139	0,1180	0,2510	-2,5222
PA	6	0,5667	0,5700	Multiple	1	0,2100	0,0064	0,0797	-0,3503	-1,2570
POM	3	0,8067	0,7000	Multiple	1	0,6400	0,1109	0,3331	1,2933	-

Fig. 5. Strength of the adhesive joints of polymer materials
Rys. 5. Wytrzymałość połączeń klejowych polimerów



The results of the tests

The results of the parameters of descriptive statistics

The parameters of the descriptive statistics of the selected polymer materials are found in Tab.2.

Six joints for each material to be bonded were performed. In the case of adhesive joint of polyacetal, 3 unsuccessful samples of destructive tests on adhesive joints were discarded. The rejection of the results of the part of adhesive joints of polyacetal is caused by obtaining the results of inconsiderable strength, the value of which was found below 0.10 MPa. The remaining obtained values of adhesive joints have been approved. When analysing the results given in Tab. 2, we may notice the absence of kurtosis for the adhesive joints of polyacetal. It is caused by the size of the test. To obtain the result of kurtosis, the number size of the trial should amount to minimum 4.

Summary of the results of the strength tests

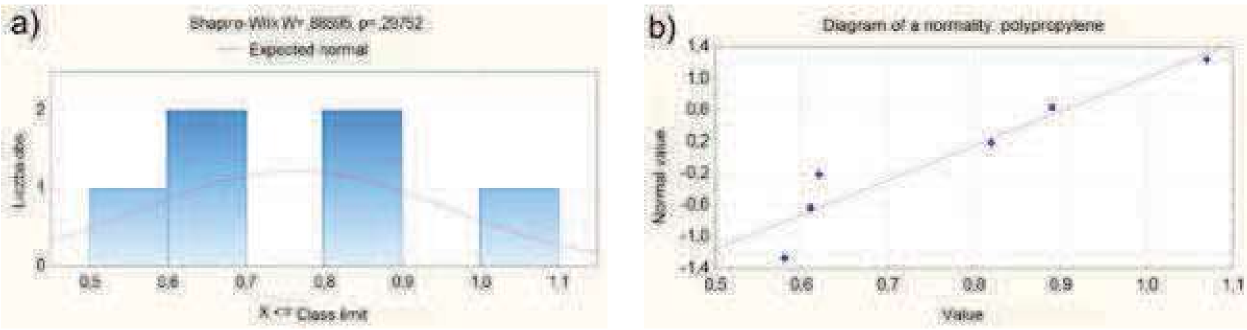
The comparison of the obtained mean results of the destructive force of the tested adhesive joints of polymer materials is shown in Fig. 5. The diagram is divided according to the adhesive applied.

It can be seen from the diagram, showing the strength of adhesive joints that the highest strength value was obtained by the adhesive joint of polystyrene. In the above mentioned bonding, the highest standard deviation was also found. From among the examined joints, in respect of the type of the adhesive used, the highest value of the strength was recorded in the case of polystyrene. Any of the destructive tests for the mentioned joint has not been discarded; however, the adhesive joint of polystyrene revealed the highest standard deviation. Fig. 5 shows a visible distribution of strength values for the discussed adhesive joint. When comparing all obtained strength

Tab. 3. The results of the test, checking a normal distribution, using Shapiro-Wilk test
Tab. 3. Wyniki testu sprawdzające rozkład normalny wykorzystując test Shapiro-Wilka

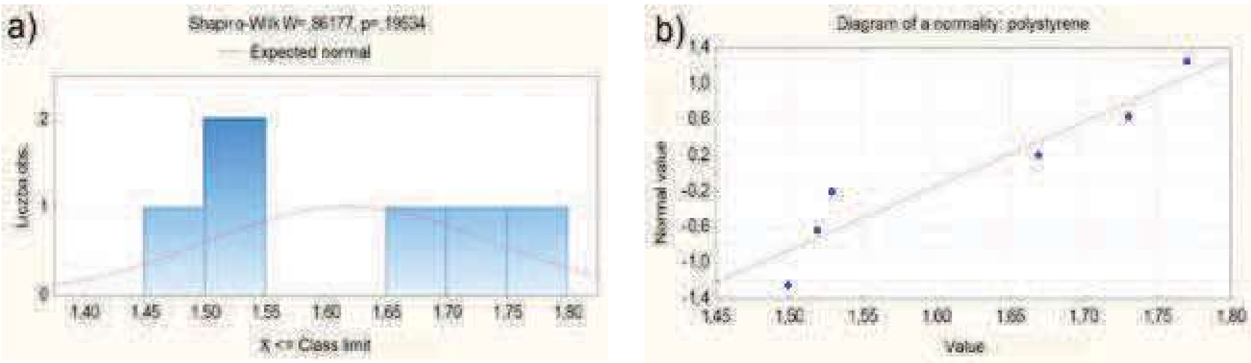
Assumptions	H_0: The tested sample has a normal distribution		
	H_1: The tested sample has not a normal distribution		
	α=0,05		
Polimer	W	P	Result
PP	0,886	0,298	p>α, no basis for rejection of H_0
PS	0,862	0,195	p>α, no basis for rejection of H_0
PA	0,937	0,64	p>α, no basis for rejection of H_0
POM	0,920	0,453	p>α, no basis for rejection of H_0

Fig. 6. Histogram of the strength (a) and diagram of a normality of distribution (b) of adhesive joints of propylene
Rys. 6. Histogram wytrzymałości (a) oraz wykres rozkładu normalności (b) połączeń klejowych polipropylenu



Normal value

Fig. 7. Histogram of the strength (a) and diagram of the normality of distribution (b) of adhesive joints of polystyrene
Rys. 7. Histogram wytrzymałości (a) oraz wykres rozkładu normalności (b) połączeń klejowych polistyrenu



Tab. 4. The comparative statistics of polymer materials, using t-student test for independent samples
Tab. 4. Statystyka porównawcza polimerów wykorzystująca test t-studenta dla prób niezależnych

Samples	Hypothesis	$t_{oread\ out.}$	$T_{calcul.}$	Result
PP-PS	$H_0: \bar{X}_1 = \bar{X}_2$	-9,17	2,23	-9,17 ∊ (-∞;-2,23> U <2,23;∞) Rejection of hypothesis H_0 $H_0: \bar{X}_1 \neq \bar{X}_2$
PA-POM	$H_0: \bar{X}_3 = \bar{X}_4$	-1,13	2,36	-1,13 ∉ (-∞;-2,36>U <2,36;∞) Lack of basis for rejection of hypothesis H_0

values of adhesive joints, we may state that the adhesive joint of polystyrene obtained the highest result.

Statistical analysis of the results of the strength tests

The obtained results of the strength tests of adhesive joints were subjected to the statistical analysis. In Fig. 6-9, the histograms of the strength and diagrams of a normal distribution for the tested adhesive joints of polymer materials were shown. To this end, Shapiro-Wilk test was applied; the mentioned test is destined for checking small populations, being found in the interval of 3-50 of the tested values. The mentioned test is also characterized by a high power of the test [13]. The results of the Shapiro-Wilk test have been given in Tab. 3. They showed that all the samples subjected to the test obtained a normal distribution.

In further analysis, t-student test was applied for independent trials [12] in order to check whether a difference in the number of the samples of adhesive joints had a statistical effect on the comparison of two adhesive joints. The results of the mentioned test are given in Tab. 4.

Fig. 8. Histogram of the strength (a) and diagram of the normality of distribution (b) of adhesive joints of polyamide
Rys. 8. Histogram wytrzymałości (a) oraz wykres rozkładu normalności (b) połączeń klejowych poliamidu

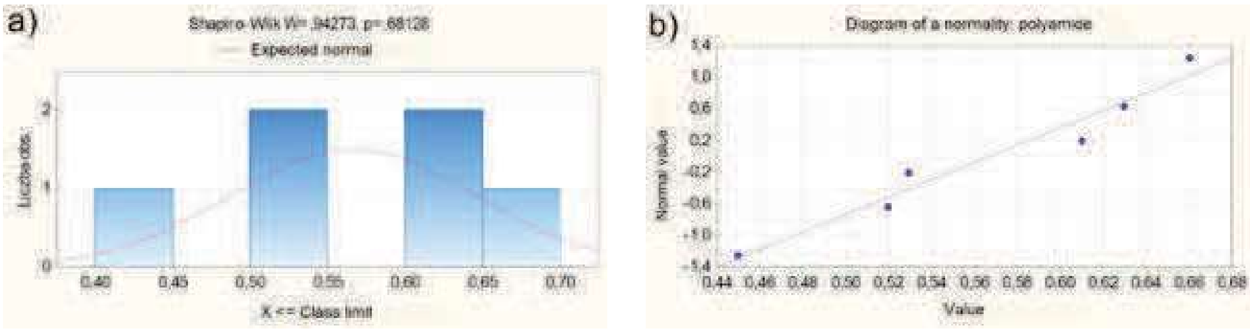
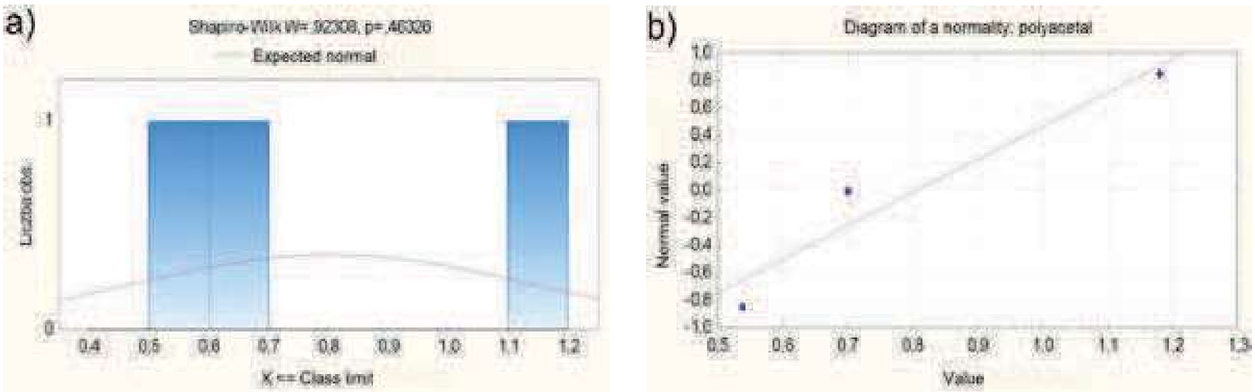


Fig. 9. Histogram of the strength (a) and diagram of the normality of distribution (b) of adhesive joints of polyacetal
Rys. 9. Histogram wytrzymałości (a) oraz wykres rozkładu normalności (b) połączeń klejowych poliacetalu



When analysing the results of the obtained values of the t-student test, comparing the adhesive joints of polymer materials in relation to the applied adhesive composition, it may be stated that only in the case of one of two variants, the basis for rejection of hypothesis Ho does not exist. Variant that meets the mentioned hypothesis is the comparison of the values of adhesive joints where the adhesive composition of epoxy resin Epidian 6 and the hardener TFF were used. In the case of t-student test of adhesive joints with the adhesive consisting of epoxy resin Epidian 6 and the hardener IDA, the hypothesis Ho was rejected. The mean strength results differ each other what can be visible in Fig. 5.

Summary

After conducting the statistical test, the following conclusions may be formulates:

- For the adhesive composition of epoxy resin Epidian 6 and the hardener TFF, the obtained result of statistical analysis of the strength of adhesive joints of polyamide and polyacetal, using t-student test meet the hypothesis on equality of the means;
- When comparing the strength of adhesive joints using Epidian 6/IDA/100:50, it may be observed that they do not meet hypothesis Ho what is an evidence of a high discrepancy of the obtained strengths of the joints;
- The highest strength value was obtained by the adhesive joint of polystyrene; the mentioned values is not equal statistically to the remaining results;
- Epoxy adhesives do not find the application in joining the elements in car vehicles, produced from the examined elements due to the obtained small strength.

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