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THE EFFECT OF DIFFERENT SURFACE TREATMENTS OF 316L STEEL ON ADHESIVE JOINT STRENGTH

Key words: surface layer, surface roughness, 316L steel, adhesive joint.

Abstract: The present paper examines selected strength test results of adhesive joints of 316L steel after different types of surface treatment. The analysis focuses on the effect of surface layer treatment on the value of selected 2D and 3D surface roughness parameters with regards to adhesive joint strength. In addition, the Abbott-Firestone curve (bearing area curve) is examined in order to provide information on the state of the surface in terms of its suitability for adhesive joining. Experimental data from shear strength tests of 316L steel specimens bonded with Loctite EA 9466 was subjected to comparative analysis. The final section draws conclusions from the study.

Analiza porównawcza przygotowania powierzchni stali 316L na wytrzymałość połączeń klejowych

Słowa kluczowe: warstwa wierzchnia, chropowatość powierzchni, stal 316L, połączenie klejowe.

Streszczenie: W pracy przedstawiono wybrane wyniki badań dotyczące skuteczności klejenia stali 316L po różnych sposobach przygotowania powierzchni. Analizowano wpływ przygotowania warstwy wierzchniej na wartości wybranych parametrów chropowatości powierzchni 2D oraz 3D w aspekcie wytrzymałości połączeń klejowych. Ponadto analizie poddano krzywą Abbotta-Firestone`a (krzywa udziału nośnego), która zawiera informacje o stanie powierzchni w aspekcie jej przydatności eksploatacyjnej. Zestawiono wyniki uzyskanych naprężeń ścinających w badaniach eksperymentalnych dla próbek wykonanych ze stali 316L z udziałem kleju Loctite EA 9466. Pracę zakończono wnioskami.

Introduction

Adhesive joining is found in an increasing scope of applications on account of numerous advantages of this method [5, 7, 9]. Cost-wise, the method enables reducing costs of joint assembly, which furthermore leads to lowering assembly and production costs of technical objects where adhesive joining is applied [6, 8]. In addition, the mass of such objects is reduced. What is more, adhesive bonding is capable of forming joints between adherends dissimilar in material, shape, or dimensions. Nowadays, the range of adhesives is enormous, hence the selection of an optimal solution in a given case is facilitated [13, 14].

Unlike in welding or pressure welding, adhesive joining does not lead to structural changes in the substrate material, nor does it require elevated temperature in the joint area, which could be the cause of thermal deformation [5, 7]. When bonding with adhesives, no holes need to be drilled in substrate material (as in riveted joints), which may lead to weakening of the cross-section and unfavourable stress-concentration in the joint. An adhesive joint is capable of dampening vibration, sealing, and air-tight sealing structures. Proper surface pre-treatment is critical to adhesive joining, and it must produce a proper surface texture and its multi-directional lay.

The geometric structure of a surface is generally described by its three main properties: shape, waviness, and roughness [1–4]. Surface roughness is most frequently evaluated in tests by quantitative measures, referred to as 2D (profile method) or 3D (stereometric method) surface roughness parameters. There are 4 groups of surface roughness parameters: measured in the vertical direction (amplitude parameters – account for changes in height), measured in the horizontal direction (spatial parameters – describe changes in width), hybrid parameters and functional parameters connected with material ratio, calculated on the Abbott-Firestone curve [1, 4, 10–12].

The aim of the article was to a conduct comparative analysis of 316L steel adhesive joints bonded with Loctite EA 9466 reflecting the impact of different surface treatment methods.

1. Methodology of measurements

The chemical composition and selected properties of 316L steel, the substrate material in tests, are shown in Table 1. The table was based on the material data sheet.

Table 1. Chemical composition and selected properties of 316L steel (according to material data sheet)

316L steel									
Element	C	Si	Mn	P	S	Ni	Cr	Mo	N
Value [%]	0.011	0.54	1.03	0.040	0.001	10.18	16.71	2.05	0.020
Tensile strength Rm [MPa]						592			
Contractual yield strength Rp0.2 [MPa]						290			
Hardness [HV]						148			

Table 2 shows different variants of surface layer preparation of 316L steel substrate specimens. Specimens sized 100x25 mm and 1.5 mm in thickness were subjected to 5 variants of surface treatment, followed by degreasing with Loctite 7061 degreasing agent. The degreasing process consisted of two stages: first the samples were treated with degreasing solution and wiped with a paper towel (repeated twice), then, after the second application of Loctite 7061, the substance was left to evaporate. Treatment operations involved the use of non-woven abrasive fabric (P280 and P100) or an abrasive tool, and they were carried out manually. Sand blasting was conducted at the pressure of 0.8 MPa.

Table 2. Substrate surface treatment variants

Variant	Surface treatment
T1	Untreated
T2	Abrasive fabric P280
T3	Abrasive fabric P100
T4	Abrasive tool P320
T5	Sand blasting

Following surface treatment, the specimens were subjected to surface roughness measurements, and the obtained results underwent further analysis.

The set-up utilised in the surface roughness measurements conducted in the study was roughness, contour, and a 3D topography measurement system T8000 RC-120-400 by Hommel-Etamic. The system was fitted with a 2 µm contour probe. The roughness sampling cut-off was obtained from literature [4].

The contact measurement method consists in reflecting peaks and valleys on the specimen surface with a measuring tip (contour probe) of a specified diameter moving on the surface of a specimen at a constant speed. The measurement is taken in a specified direction in the 2D profile; whereas, the 3D stereometric method employs a line-profiling method carried out on a specified surface. The specimens were scanned in the area of 4.8 mm x 4.8 mm. 2D surface roughness parameters were taken in ten repetitions for all surface treatment variants, and their mean values, including standard deviation, were presented in the form of graphs.

Surface roughness parameters measurement provides a thorough evaluation of its microgeometry. Surface topography, particularly roughness, and waviness is characterised by a number of parameters. The conducted tests focused on the following 3D area roughness parameters of the surface:

- Sq – root mean square height,
- Sz – maximum height,
- Sa – arithmetical mean height.

The tests conducted for the sake of this study involved the measurement of the following 2D surface roughness parameters:

- Ra – arithmetic mean deviation of the roughness profile,
- Rk – core roughness depth,
- Rt – total height of the profile,
- Rz – maximum height of the profile.

Figure 1 shows a schematic representation of the tested single lap adhesive joint. Bondline thickness was gk = (0.07 – 0.09) mm, and the remaining dimensions are shown in Fig. 1.

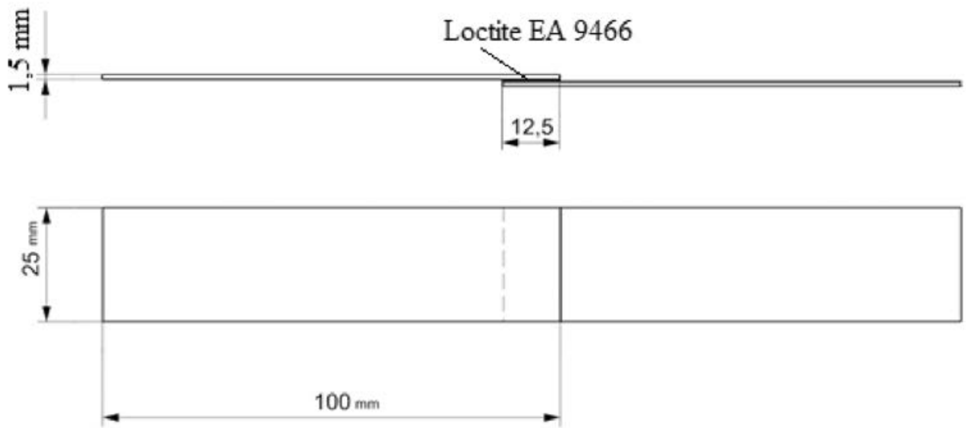


Fig. 1. Schematic representation of the single lap adhesive joint

The adhesive was cured at ambient temperature of (22–24)°C and the relative humidity of (45–55)%. The value of load applied to the joint during cure, expressed in MPa, was specified at 0.2 MPa, and the curing time was 168 h.

Table 3 shows selected properties of cured Loctite EA 9466 adhesive composition.

Table 3. Selected properties of cured Loctite EA 9466 adhesive [15]

Physical properties	Loctite EA 9466
Tensile strength (ASTM D882), N/mm^2	32
Elongation (ASTM D882), %	3
Tensile modulus (ASTM D882), N/mm^2	1718
Shore hardness (ASTM D1706), Durometer D	60

The instrument used to produce an image of 316L steel substrate surface was a Keyence VHX-5000 microscope.

Adhesive joint shear strength was evaluated according to the standard DIN EN 1465 by means of a Zwick/Roell Z 150 material testing machine. The initial distance between grips was equal to 85 mm, and the traverse speed was set to 2 mm/min. Each series of tests was conducted on ten specimens.

2. Test results

Table 4 shows 3D isometric images of 316L steel substrate specimens after particular surface treatment operations, selected 3D area roughness parameters, as well as microscopic images of specimens magnified 1000 times.

The observations and analysis of test results show that it is the surface treatment variant T5 (sandblasting) that provides the best results of surface preparation for adhesive bonding. It may be noted that the value of Sa area roughness parameter is 6 times higher compared to the untreated surface T1. As a result of kinematic tool interference, the geometric structure of 316L steel specimen surface subjected to abrasive fabric treatment shows distinct tool marks.

Table 5 shows selected surface roughness profiles of 316L steel specimen and includes the Abbott-Firestone curve (bearing area curve) calculated for all the surface treatment variants. An interesting observation is the positive correlation between the surface profiles and the substrate bond surface texturing.

The Abbott-Firestone curve contains information regarding the state of the surface with respect to its suitability for bonding. The selected parameter of the Abbott-Firestone curve was Rk – core roughness depth, i.e. the part of the profile excluding extreme peaks and depths.

Figure 2 shows the effect of different surface treatment variants of 316L steel substrates on the Rk surface roughness parameter.

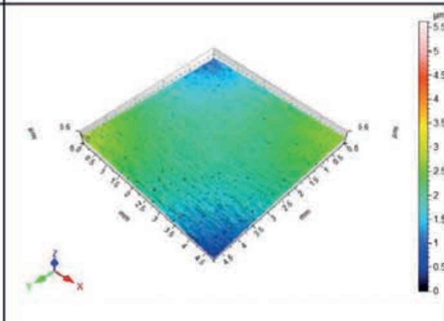
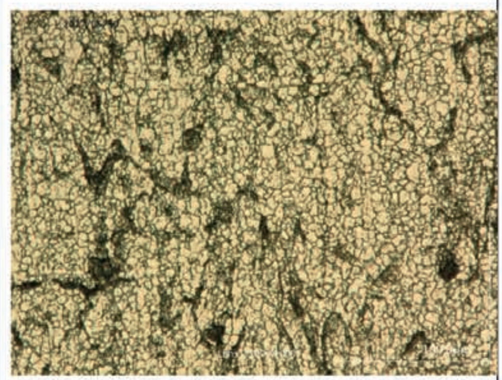
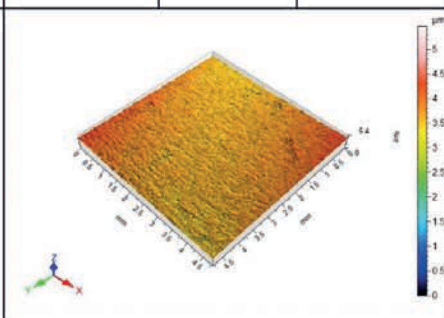
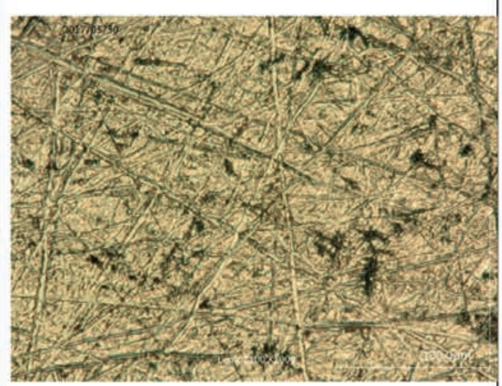
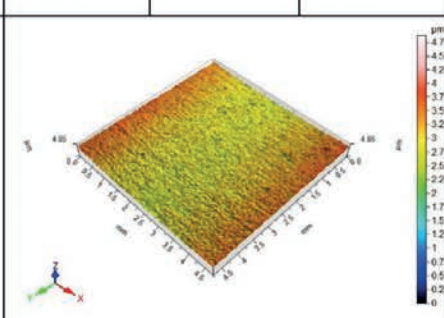
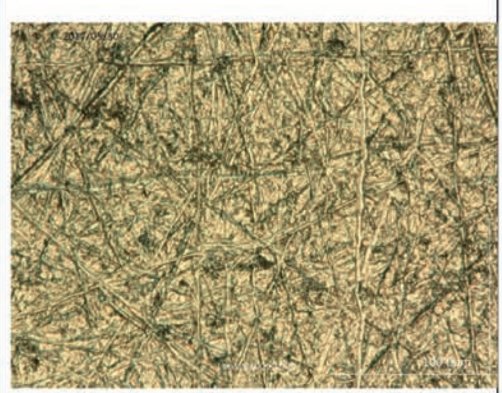
The conducted analysis evidences a 36-fold increase in the value of Rk for surface treatment variant T5 in comparison with the untreated variant T1. In the first four variants (T1-T4), the standard deviation does not exceed 0.07.

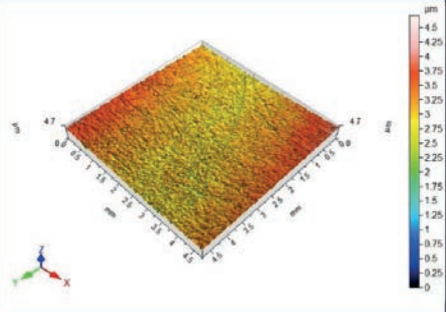
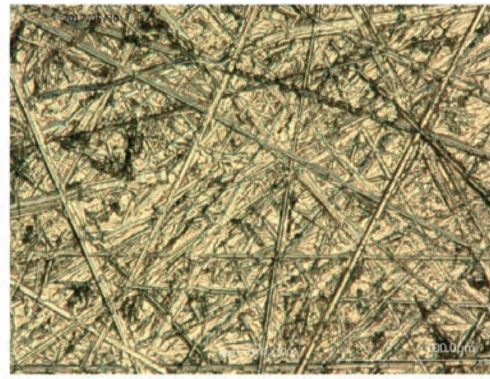
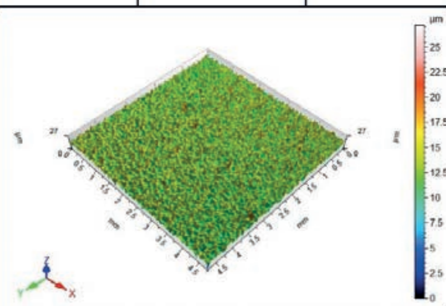
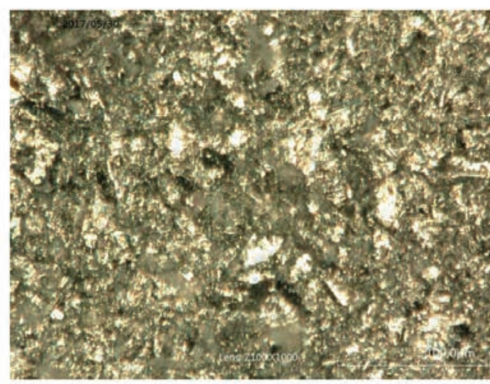
Figure 3 shows the impact of particular surface treatment methods on the value Ra of the surface roughness parameter.

Both Rk and Ra parameters seem to show a similar relationship with the particular surface treatment variants. In T2-T4, the value of surface roughness parameter Ra ranges between (0.14–0.19) μm. The scatter of results is the standard deviation.

Fig. 4 shows the relationship between Rz/Rt surface roughness parameters and different surface treatment methods.

Table 4. Isometric images and images of the specimens' surfaces

Variant	Isometric image 3D			Picture x 1000
T1				
	Selected parameters of surface roughness 3D			
	Sq [µm]	Sz [µm]	Sa [µm]	
	0.376	5.62	0.285	
T2				
	Selected parameters of surface roughness 3D			
	Sq [µm]	Sz [µm]	Sa [µm]	
	0.214	5.46	0.158	
T3				
	Selected parameters of surface roughness 3D			
	Sq [µm]	Sz [µm]	Sa [µm]	
	0.271	4.87	0.212	

<table>
<tr><td rowspan="4">T4</td><td colspan="3"></td><td rowspan="4"></td></tr>
<tr><td colspan="3">Selected parameters of surface roughness 3D</td></tr>
<tr><td>Sq [µm]</td><td>Sz [µm]</td><td>Sa [µm]</td></tr>
<tr><td>0.294</td><td>3.15</td><td>0.226</td></tr>
<tr><td rowspan="4">T5</td><td colspan="3"></td><td rowspan="4"></td></tr>
<tr><td colspan="3">Selected parameters of surface roughness 3D</td></tr>
<tr><td>Sq [µm]</td><td>Sz [µm]</td><td>Sa [µm]</td></tr>
<tr><td>2.23</td><td>27.4</td><td>1.75</td></tr>
</table>

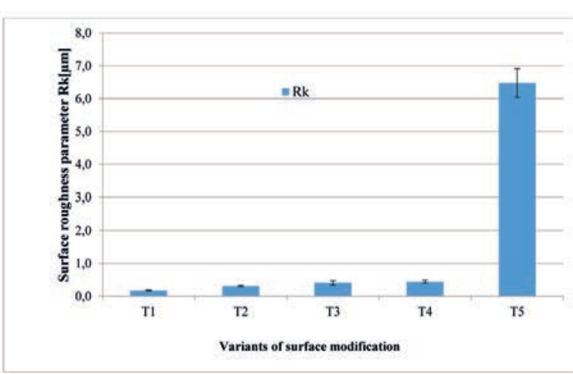


Fig. 2. The effect of surface treatment on surface roughness parameter Rk

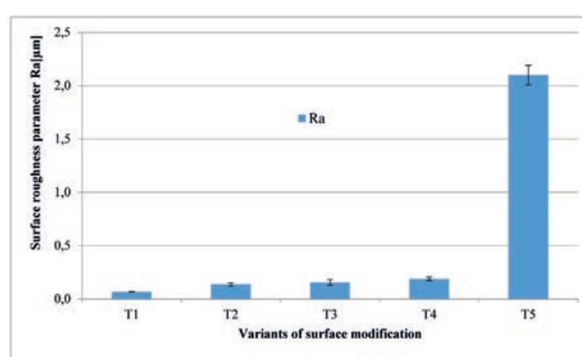
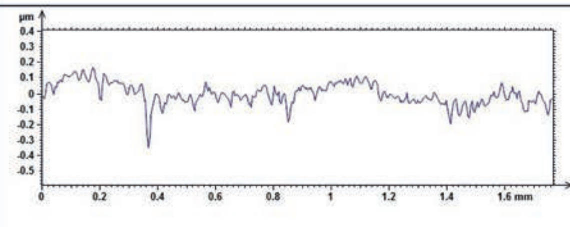
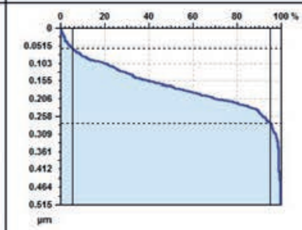
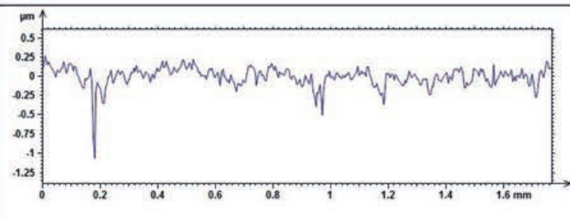
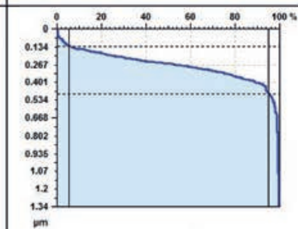
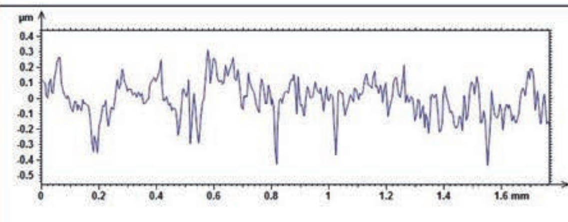
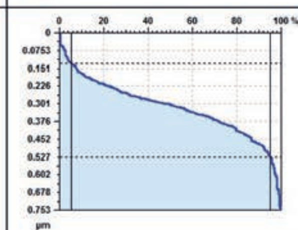
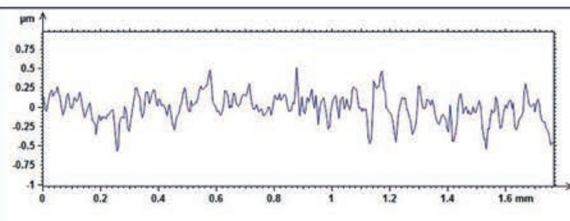
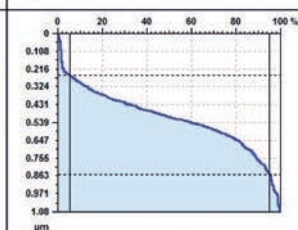
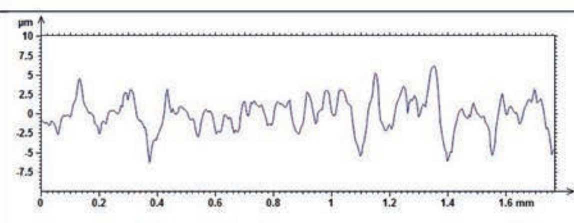
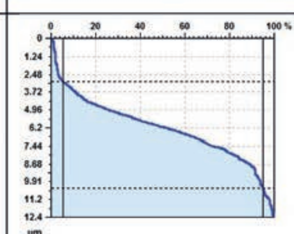


Fig. 3. The effect of surface treatment on the value of surface roughness parameter Ra

Table 5. 2D surface roughness parameters and the Abbott-Firestone curves

Variant	Profile of roughness	Abbott-Firestone curves
T1		
T2		
T3		
T4		
T5		

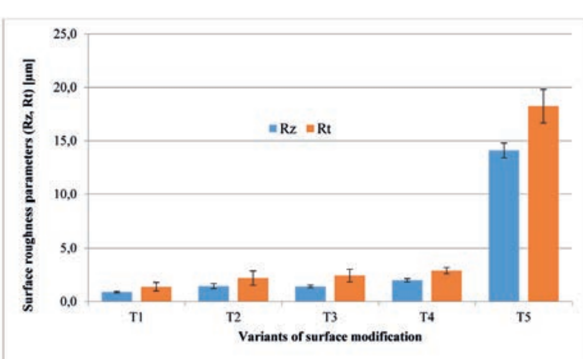


Fig. 4. The effect of surface treatment on the value of surface roughness parameters Rz and Rt

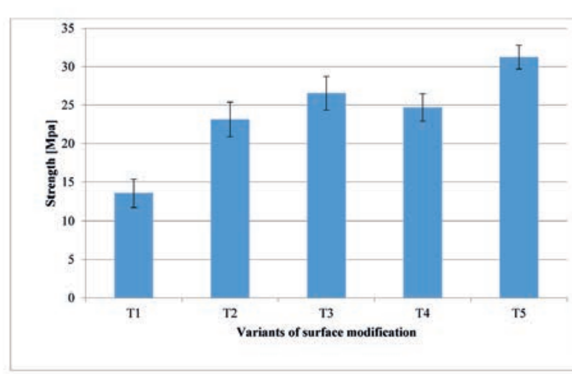


Fig. 5. Shear stress of 316L steel adhesive joint specimen bonded with Loctite EA 9466

The analysis of results indicates a small increase of Rt compared to Rz. The standard deviation for Rt is twice as high as for Rz. In addition, a notable increase in the values of both surface roughness parameters is observed for the T5 surface treatment method. The values of the parameters in question increase 15x.

Figure 5 shows shear stress values obtained from strength tests of 316L steel adhesive joint specimens bonded with Loctite EA 9466.

The strength tests conducted in the study show that the highest shear failure stress is obtained for the surface treatment variant T5 – sandblasting. The average value of these strains amounts to approx. 31 MPa, which exhibits a 130% increase in the value of shear failure stress in comparison with untreated specimens (T1). Moreover, the repeatability of measurements for all surface treatment variants was very good, as confirmed by the level-2 standard deviation. The lowest increase in the value of shear stress was observed for samples subjected to variant T2 of surface treatment, which produced a 70% increase in shear stress compared to T1.

Conclusions

The tests and analyses conducted as a part of the research work presented in the present paper allowed us to formulate the following conclusions:

1. The results of surface roughness profile measurements indicate sandblasting as the most effective method of producing the desired surface texture of the analysed specimens.
2. The highest surface roughness and area roughness parameters were obtained for specimens subjected to the T5 surface treatment method (sandblasting).
3. The highest strength of adhesive joints was observed in sandblasting-treated specimens (T5). The increase in joint strength amounted to 130%, compared to joints whose substrates were untreated (T1).

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