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EFFECT OF OVERLAP LENGTH ON THE STRENGTH OF ADHESIVE JOINTS OF STEEL SHEETS

WPŁYW DŁUGOŚCI ZAKŁADKI NA WYTRZYMAŁOŚĆ POŁĄCZEŃ KLEJOWYCH BLACH STALOWYCH

Abstract

The study evaluates the shear strength of the single-lap adhesive joints made of C45 carbon steel. The influence of the overlap length on the shear strength of the adhesive joint was tested. The elongation of the samples was also tested. Before the bonding process, the samples were treated with P180 abrasive paper and degreased. The adhesive joints were made using the Epidian 53/Z1/100:10 adhesive composition. The strength tests were carried out on a Zwick/Roell Z150 testing machine. The maximum value of the shear strength was obtained for the lap L_{z1} = 13 mm and the minimum for L_{z4} = 19 mm.

Keywords: adhesive joint, shear strength, elongation, overlap length

Streszczenie

W pracy dokonano oceny wpływu długości zakładki na wytrzymałość na ścinanie jednozakładkowych połączeń klejonych wykonanych ze stali węglowej C45. Podczas eksperymentu zbadano także wydłużenie próbek. Przed rozpoczęciem procesu klejenia próbki zostały obrobione papierem ściernym P180 i odtłuszczone. Połączenia klejowe wykonano przy użyciu kompozycji klejowej Epidian 53/Z1/100:10. Badania wytrzymałościowe przeprowadzono na maszynie wytrzymałościowej Zwick/Roell Z150. Maksymalną wartość wytrzymałości na ścinanie uzyskano dla długości zakładki L_{z1} = 13 mm, a minimalną dla L_{z4} = 19 mm.

Słowa kluczowe: połączenie klejowe, wytrzymałość na ścianianie, wydłużenie, długość zakładki

1. Introduction

The continuous development of the bonding process is associated with the use of adhesive joints in many fields of industries, including the aviation, shipbuilding, transport, medicine and construction [1-3].

The bonding is a complex process because it covers many issues related to the phenomenon of adhesion, but also the problem of choosing adhesive and material, technology of making joints and their strength [4-6].

The strength properties of adhesive joints depend on the adhesive technology, including surface treatment, adhesive preparation and application and the curing conditions [7,8]. The strength of adhesive joints is defined as the joint's resistance to the damaging effects of mechanical and thermo-mechanical factors. It is also referred to as load capacity. The condition for proper design of the adhesive joints is achieving a specific static strength of the adhesive joint. The strength of the adhesive joints can be adjusted by changing the dimensions of the adhesive joint. The maximum strength of compression joints and even peeling occurs for the thinnest joints. The

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joint thickness is controlled by applying appropriate pressure during the bonding process [9-14].

Volkersen determined the shear stress distribution of lap adhesive joints, assuming the following:

- adhesive joints and elements behave like linear elastic bodies,
- adherends in all sections are evenly stretched,
- eccentricity of load action, causing bending of joined elements does not affect the distribution of shear stress in the adhesive joint [15, 16].

The shear strength is one of the most commonly used methods to control the adhesive joints. It makes it possible to reconstruct and measure the strength of a structural element in standard operating conditions. The shear strength is directly proportional to the width of the sample [16-18].

Factors affecting the strength of adhesive joints can be divided into structural, material and technological groups. Achieving the adhesive joints with appropriate properties and strength requires consideration of all the above-mentioned aspects. The single-lap adhesive joints are, next to double-lap adhesive joints, the most frequently used adhesive joints in practice. They are usually used to joint materials of relatively small thicknesses. Due to the simple geometry and easy assembly they are treated as easy to make adhesive joints. The main structural factors include the overlap length, thickness of adherends, thickness of adhesive joints, stiffness of the elements, stiffness of the adhesive, size of the spew fillet, bevelling of the end of the lap, method of constituting the joints [15, 19, 20]. Operating conditions also have a significant influence on the strength of the adhesive joint. One of the main operational factors affecting the reduction of adhesive and cohesive strength is temperature [21].

This study investigates the effect of the overlap length on the strength of steel sheet adhesive joints.

2. Materials and methods

The single-lap adhesive joint specimens made of C45 carbon steel were tested. The shape and dimensions of the samples are shown in Fig. 1.

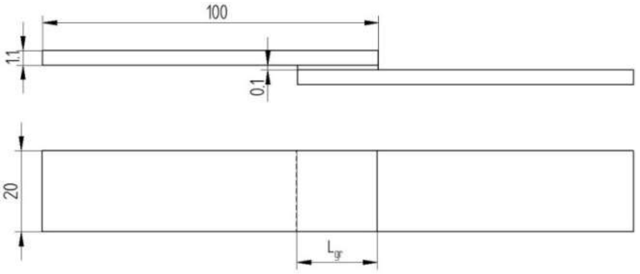

Fig. 1. Tested adhesive joints

The border length of the lap L_{gr} was calculated on the basis of formula (1) assuming the same thickness of the joined sheets [15, 16].

$$L_{gr} \geq 5\sqrt{\frac{E\delta\delta_k}{2G_k}} \tag{1}$$

The dimensions of joints assembled in the study were:

$E = 2.1 \times 10^5$ MPa – Young's modulus of the adherends,
$\delta = 1.1$ mm – thickness of the adherends,
$\delta_k = 0.1$ mm – thickness of the adhesive layer,
$G_k = 1000$ MPa – shear modulus of adhesive.

Based on the L_{gr}, there were selected 5 overlap lengths: two lower and two higher than the border length (Table 1).

Table 1. Overlap lengths

Mark	Overlap length
L_{z1}	13 mm
L_{z2}	15 mm
$L_{z3} = L_{gr}$	17 mm
L_{z4}	19 mm
L_{z5}	21 mm

The sheets were prepared with P180 abrasive paper and degreasing using acetone (3 repetitions) [9]. The sheets were joined using Epidian 53 epoxy resin and triethylenetetramine curing agent (Z-1, trade name), mixed in a ratio of 100:10 (Epidian 53/Z1/ 100:10), applied on the one of the surface. The temperature during the joining process was 25°C±1°C and humidity 32%±2%. The samples were cured for 7 days under a load of 0.09 MPa. After this period, the samples were subjected to the strength tests on a Zwick/Roell Z150 testing machine in accordance with the recommendations of PN-EN:1465:2009 standard. The test speed was 5 mm/min.

3. Results

The results of strength tests of the single-lap adhesive joints are presented in Fig. 2. The error bars shown in Fig. 2 and Fig. 3 represent the standard deviation.

The highest value of the shear strength (4.37 MPa) was obtained for the overlap length L_{z1} = 13 mm and the lowest (3.40 MPa) for the length L_{z4} = 19 mm. The strength of the adhesive joint with a border length (L_{z3} = 17 mm) was 3.71 MPa. The difference between the extremes of the obtained strength resulted was about 22%. The disproportion between the maximum strength value and the value obtained for the border length was 15% and between the minimum and L_{gr} was nearly 8.4%.

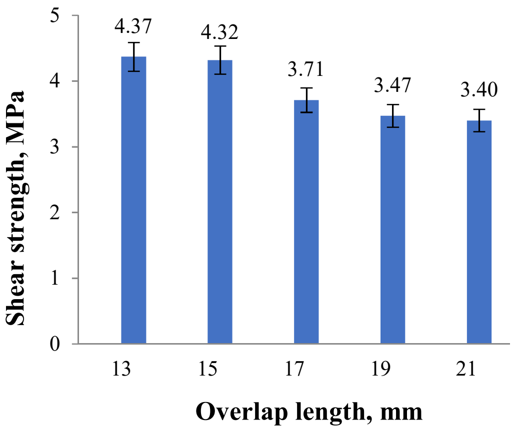

Fig. 2. Shear strength results

The effect of the overlap length on the shear strength was analysed using one-factor ANOVA (Table 2). The statistical analysis were performed using Statistica program at the confidence interval $\alpha = 0.05$. It can be seen that the tested factor does not significantly affected the strength result.

The Pearson linear correlation coefficient r was used to investigate the correlation between the tested factors. It was noticed that the r-Value was about -0.49, which proves a moderate linear correlation between the shear strength and the overlap length. Based on the coefficient of determination (r^2) it can be stated that 25% shear strength is explained by the variability of the overlap length (Table 3).

Table 2. One-factor ANOVA for shear strength

Source	Sum of Squares	df	Mean Square	F-Ratio	p-Value
Overlap length	4.17	4	1.04	2.00	0.13
Total error	10.42	20	0.52		
Total (corrected)	14.59	24			

Table 3. Correlations of shear strength and overlap length

Correlation	Mean	Standard deviation	r	r^2	t	p-Value
shear strength vs overlap length	3.85	0.78	-0.49	0.24	-2.72	0.01

Fig. 3 shows the results of the elongation of the adhesive joints. The highest average value of elongation (0.38 mm) was obtained for the lap $L_{z2} = 15$ mm, and the lowest (0.28 mm) for the adhesive joint with the overlap length $L_{z1} = 13$ mm. The difference between the extremes was almost 26%. The elongation value obtained for the border length. L_{gr} was more than 5% lower than the maximum elongation value.

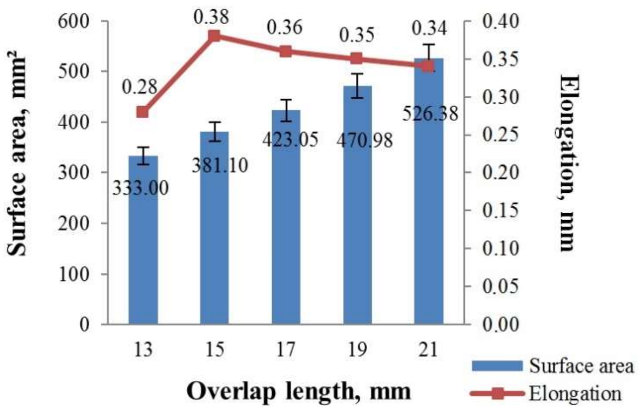

Fig. 3. Elongation results

4. Summary

The purpose of the work was to determine the overlap length on the strength of the single-lap adhesive joints. Analyzing the above results, it can be seen that the overlap length affects the strength of the adhesive joint. This result is in agreement with the literature [10, 23]. The maximum value of the shear strength was obtained for the shortest lap ($L_{z1} = 13$ mm), hence it can be concluded that a shorter lap increases the strength of the adhesive joint.

The statistical analysis showed the change of the tested factor did not statistically significantly affect the strength of the adhesive joints ($p > 0.05$). On the other hand, there was a moderate correlation between the studied variables. It can be concluded that strength of adhesive joint cannot be clearly predicted, therefore experimental testing is required.

It was also noticed that with the increase in the overlap length (starting from the border lap L_{gr}), there was a decrease in the elongation of the samples.

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