EFFECT OF THE SURFACE TREATMENT ON THE STRENGTH OF THE SINGLE-LAP ADHESIVE JOINTS

Wpływ obróbki powierzchniowej na wytrzymałość jednozakładkowych połączeń klejowych

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DOI: 10.15199/160.2021.1.3

A b s t r a c t: The paper analyzed the shear strength of the single-lap adhesive joints made of zinc galvanized coat of steel sheet. Mechanical treatment of the samples was carried out using P120, P180, P220, P400 and P600 abrasive papers. In the experiment were used two variants of surface treatment: with a degreaser and without a degreaser.A two-component epoxy adhesive Epidian 53/IDA/100:40 was used to make the joints.The strength tests were carried out on a Zwick/Roell Z150 testing machine, PN-EN 1465 standard. The article contains also the results of the maximum force and the values of the surface roughness parameters (*Ra*, *Rz*, *Rq*) of the samples prepared without a degreaser. The measurements of surface roughness parameters (*Ra*, *Rz*, *Rq*) were made using a HOMMEL TESTER T1000 profilometer, according to PN-EN ISO 4287. The maximum value of the shear strength (2.70 MPa) was obtained for the samples prepared with P220 abrasive paper using a degreaser and the lowest (1.02 MPa) for the samples prepared with P180 abrasive paper using a degreaser.
K e y w o r d s: adhesive joint, shear strength, surface treatment, surface roughness

S t r e s z c z e n i e: W artykule przeanalizowano wytrzymałość na ścinanie jednozakładkowych połączeń klejowych wykonanych z ocynkowanej powłoki blachy stalowej. Obróbkę mechaniczną próbek przeprowadzono przy użyciu papierów ściernych P120, P180, P220, P400 i P600. W eksperymencie zastosowano dwa warianty obróbki powierzchni: z odtłuszczaczem i bez odtłuszczacza. Do wykonania połączeń użyto dwuskładnikowego kleju epoksydowego Epidian 53/IDA/100:40. Badania wytrzymałościowe przeprowadzono na maszynie wytrzymałościowej Zwick/Roell Z150, norma PN-EN 1465. W artykule zamieszczono również wyniki pomiaru siły maksymalnej oraz wartości parametrów chropowatości powierzchni (*Ra*, *Rz*, *Rq*) próbek przygotowanych bez odtłuszczacza. Pomiary parametrów chropowatości powierzchni (*Ra*, *Rz*, *Rq*) wykonano przy użyciu profilometru HOMMEL TESTER T1000, zgodnie z normą PN-EN ISO 4287. Maksymalną wartość wytrzymałości na ścinanie (2,70 MPa) uzyskano dla próbek przygotowanych papierem ściernym P220 z użyciem odtłuszczacza, a najmniejszą (1,02 MPa) dla próbek przygotowanych papierem ściernym P180 z użyciem odtłuszczacza.
S ł o w a k l u c z o w e: spoina klejowa, wytrzymałość na ścinanie, obróbka powierzchniowa, chropowatość powierzchni

Introduction

Due to the growing demand for lightweight constructions, it is necessary to modify the methods used for joining materials. Bonding is one of the alternatives to traditional joining techniques such as mechanical fasteners or welded and solders connections [4, 8, 25]. The increasing use of adhesive joints in industry is associated with a number of advantages of this type of joint, like: ability to join different materials, reduction of the weight of the structure, corrosion resistance. One of the main disadvantages of the adhesive joint is the formation of stress concentrations in the adhesive layer [9, 16, 26]. It is so important to properly design the adhesive joint, which can occur in several configurations. The most common configurations are single-lap, double-lap and scarf joints [1, 9-11].

The first stage of bonding process is surface treatment of adherends [1, 2, 6, 17-20].The process has a significant influence on the strength and durability of the future adhesive bond. The surface treatment step should be carefully carried out to ensure the strongest adhesive joints are obtained and involves geometrical surface development and removal of impurities and surface layers of oxides from them [8, 13, 19-22].Knowledge of the type, structure and properties of the materials to be joined determines the choice of the appropriate surface treatment method [3, 4, 15, 22, 26].

Bonding of galvanized steel sheets is associated with many difficulties. Commonly used methods of joining these types of materials are often the cause damage near the joint. Therefore, additional processing is necessary which protects against possible crack propagation [7, 10].The industry often uses hot-dip galvanized and electro-galvanized steel sheets, which are joined with adhesive. The treatment of galvanized steel sheets for the bonding process usually involves degreasing of joined surfaces, machining with abrasive tools, re-degreasing and etching. The use of agents with acetone for degreasing surfaces of hot-dip galvanized sheets results in increased strength of the adhesive joints 13, 19, 24].

The study was intended to determine the effect of the surface treatment (degreasing) and granulation of abrasive paper on the strength of adhesive joints made of hot-dip galvanized steel sheet.

Materials and methods

• *Adherend*

The subject of the study was a single-lap adhesive joint. DX51D Z275(PN-EN 10327) hot-dip galvanized steel sheets (1.0035 structural steel) were used in the test as the adherends. The weight of the zinc coating was 275 g/m^2. Selected mechanical properties are following (EN10346): (i) the tensile strength *Rm* is 270-500 MPa, and (ii) elongation A80 is 22% (min).The adhesive joint specimens are shown in Fig. 1.

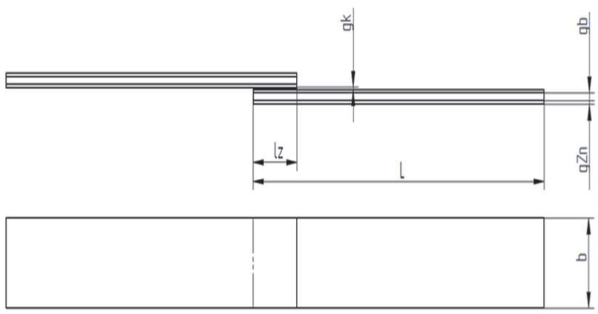

Fig. 1.Tested adhesive joints

The dimensions of the specimen were: length l=100±0,4 mm, width

b = 20 ± 0.4 mm, overlap length *lz*=15 mm, adherend thickness *gb*= 0.7±0.04 mm, adhesive layer thickness gk= 0.1 ± 0.02 mm, zinc coating thickness *gZn* = 0.018 mm.

• *Surface treatment method*

As a method of the surface treatment of hot-dip galvanized sheets, mechanical treatment with abrasive coating tools in the form of abrasive paper was used. Five abrasive paper of different gradation in the form of an A4 sheet were used for surface treatment: P120, P180, P220, P400, P600 (RS Components, Warsaw, Poland).The machining was performed using mentioned abrasive paper with 30 circular movements on each sample.

Two types of surface treatment variants were used in the experiment: with degreasing and without degreasing (Tab. 1).

Half of the samples were subjected to degreasing using acetone (PIKKO, Dragon Poland, Kraków, Poland) wiping off the wet surfaces with dust-free pads to remove impurities, as degreasing agent in 2 repetitions. In the case of degreasing, the rubbing method was used. After the second degreaser deposition, the acetone was left on the surfaces of the samples for complete evaporation (about 1 minute). The surface treatment of the second batch of samples consisted of an analogous mechanical treatment omitting the degreasing stage. The degreasing was carried out at a temperature of 25 ± 1°C and air humidity of 22 ± 1%.

• *Adhesive*

The samples were joined with a two-component epoxy adhesive consists of modified epoxy resin (Epidian 53, trade name) and amine curing agent (IDA, trade name). For epoxy resin with an epoxy number of 0,41 mol/100 g and amide curing agent with an amine number between 200 and 350 mg KOH/g, the range of this ratio is 40: 100 (amount of curing agent per 100 g of resin). The designation of epoxy adhesive is Epidian 53/IDA/100:40. The resin and amine curing agent are produced by CIECH Resins manufacturer, Nowa Sarzyna, Poland. The characteristic the epoxy adhesive components were presented in [23].The definite amount of the epoxy resin and amine curing agent were batched with an electronic scale (OX-8100 type, FAWAG S.A, Lublin, Poland, measurement accuracy 0.1 g, ISO 9001) in a polymer container. Then the epoxy adhesive components were mechanically mixed using an anchor stirrer at a speed of 460 RPM for 2 minutes on a mechanical mixing station and after that the epoxy compound was kept under vacuum for 2 minutes. The batching and mixing processes were made at temperature of 25 ± 1°C and humidity of 22 ± 1%.

The epoxy adhesive was applied on one of the surfaces to be bonded immediately after mixing. The adhesive joints were one step cold-cured for 10 days under

Table 1.Surface treatment variants–designations

Surface treatment variants	Abrasive paper				
	P120	P180	P220	P400	P600
Variant M (mechanical treatment)	MP120	MP180	MP220	MP400	MP600
Variant MD (mechanical treatment and degreasing)	MDP120	MDP180	MDP220	MDP400	MDP600

pressure of 0.09 MPa. The bonding was carried out at a temperature of 25 ± 1°C and air humidity of 22 ± 1%.

• Tests

The measurements of surface roughness parameters (Ra, Rz, Rq) were made using a HOMMEL TESTER T1000 profilometer for samples prepared with each type of abrasive paper in a variant without a degreaser (3 samples for each type of abrasive paper) according to PN-EN ISO 4287. The shear strength tests were carried out in accordance with the recommendations of PN-EN 1465standard on a Zwick/Roell Z150 testing machine (Zwick Roell GmbH & Co. KG, Ulm, Germany) assuming an initial force value of 5 N and a traverse speed of 5 mm/min.

Results

• Surface roughness parameters

The results of the measured surface roughness parameters of the single-lap adhesive joints prepared without adegreasing – Variant M (Table 1) are shown in Fig. 2.

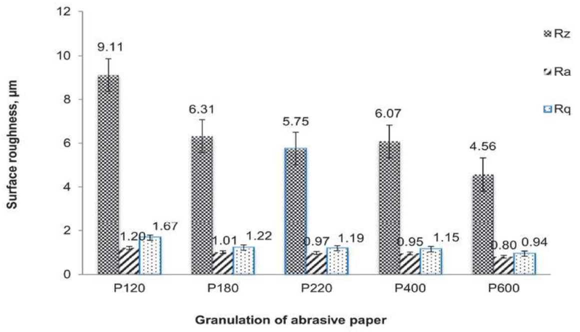

Fig. 2. Surface roughness results

Analyzing the test results presented in Fig. 2, it can be seen that for all measured surface roughness parameters, the maximum values (*Rz* = 9,11 µm, *Ra* = 1,20 µm, *Rq* = 1,67µm) were obtained for the samples treated with P120 abrasive paper and the minimum values (*Rz* = 4,56 µm, *Ra* = 0,80 µm, *Rq* = 0,94 µm) after processing with P600 abrasive paper. The differences between the extremes of individual parameters were respectively: *Rz* – 50%, *Ra* – 34% and *Rq*– 78%. For most samples, an increase in the abrasive paper grain size resulted in a decrease in the surface roughness parameters. The exception were the samples prepared using P400 abrasive paper, for which the value of *Ra* increased by almost 5% compared to the value of this parameter obtained using a lower granulation of abrasive paper, i.e. P220.

•Shear strength

The strength results of adhesive joints for both surface treatments variants are presented in Fig. 3.

The highest value of the shear strength of samples subjected to degreasing (2,70 MPa) was recorded after processing with P220 abrasive paper (MDP220). The lowest value for this variant (1,02 MPa) was observed for samples prepared with P180 abrasive paper. The difference between the extremes of variant with a degreaser was about 62%. For variant without a degreaser the highest value of the shear strength (2,53 MPa) was recorded for machining with P400 abrasive paper and the lowest (1,16 MPa) using P120 abrasive paper. These values differed by almost 54%. The difference between the maximum values of both variants was nearly 6%.

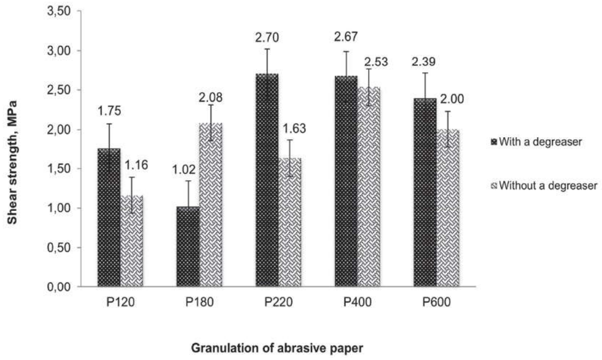

Fig. 3. Shear strength resultss

The strength results of samples treated with P120, P220, P400 and P600 abrasive papers for the variant using a degreaser were higher than for the samples prepared with the same abrasive papers without the use of a degreaser. These differences were as follows: P120 – 33 %, P220 – 40 %, P400 – 5 %, P600 – 16 %.The exceptions were the samples prepared with P180 abrasive paper without using a degreasing agent (MP180). The shear strength of samples prepared in this variant was about 50% higher than the shear strength of samples prepared with abrasive paper of the same granulation but with the use of a degreaser.

•Basic statistic analysis

The influence of the granulation of abrasive paper, surface treatment and their interaction on the shear strength was analyzed using ANOVA. It was stated that the all tested factors are not statistically significant for the shear strength ($p < 0.05$) at the 95% confidence interval (Tab. 2).

To determine the relation between the tested factors, the Pearson linear correlation coefficient r was calculated (Tab. 3).

The value of this coefficient for the granulation of abrasive paper is 0.45, which proves a moderate correlation between the shear strength and the granulation of abrasive paper. The coefficient of determination (r^2) is 0.20, which means the variability of the shear strength is in 20% explained by the variability of the granulation of abrasive paper. For the surface treatment, the *r* value is about -0.16, which indicates a weak correlation between

Table 2. ANOVA for the shear strength

Source	Sum of Squares	df	Mean Square	F-Ratio	p-Value
Variant M	6.45	4	1.61	2.68	0.05
Variant MD	0.62	1	0.62	1.03	0.32
Variant M Vs. Variant MD	4.29	4	1.07	1.78	0.16
Total error	17.45	29	0.60		
Total (corrected)	28.81	38			

Table 3. Correlations of tested factors

Correlation: shear strength vs	Mean	Standard deviation	r	r^2	p-Value
Variant M	103.56	1.77	0.45	0.20	<0.05
Variant MD	101.49	0.51	-0.16	0.02	0.34

the shear strength and the presence of the degreaser. The variation in the shear strength could be explained in 2% by variation in the presence of the degreaser (r^2 = 0.02).

Discussion

The strength of the adhesive joint is influenced by many factors. One of them is surface treatment. Prolongo and Ureña [15] noticed that pre-treatment effect depends on the adhesive nature, the order of the epoxy adhesive studied, as a function of its bonding strength remains constant. They also underlined that it scarcely depends on the applied pre-treatment. The article presents the effect of the degreasing and the surface roughing on the strength of adhesive joints made of hot-dip galvanized steel sheet. Based on the obtained results it can be stated degreasing usually allowed to obtain higher strength of the adhesive joint. Rudawska et al. [22] underlined that the strength results reveal that thesurface treatment method of galvanized metal sheets for adhesive bonding should take into account not only the type of degreasing agent but also the degreasing method, as the results reveal that these two factors have a significant effect on the strength of the tested adhesive joints. The maximum value of the shear strength in the variant with degreasing was obtained for P220 abrasive paper (MDP220) and without degreasing for P400 abrasive paper (MP400). The use of a degreasing agent is associated with the possibility of using a lower granulation of abrasive paper. In work [18] it was observed that the most advantageous method of surface preparation of structural steel C45, aluminium alloy EN AW-1050A and stainless steel 1,4401 is treatment using P220 grit abrasive paper. Analyzing the results it can be notice that the surface roughness is reasonable up to certain values. Rudawska et al. [17] also indicated that both surface roughness and adhesive properties are more affected by the type of abrasive material used rather than by variations in pressure. In addition in work [20] it was noted that with increasing roughness, the strength of the joints also increases, which confirms the influence of surface treatment on strength of adhesive joints. Optimum surface roughness is essential to obtain the maximum strength of adhesive joint [3, 11, 13] and depends on the adherends.

Conclusions

The analysis of the results allows the formulation of the following conclusions:

- the use of a degreasing during the samples treatment allowed to obtain the highest shear strength of the single-lap adhesive joints;
- the granularity of abrasive paper used for the surface treatment affects the strength of the adhesive joint;
- the maximum value of the shear strength (2,70 MPa) was obtained for the variant with a degreaser and using P220 abrasive paper;
- the minimum value of the shear strength (1,02 MPa) was obtained for the variant with a degreaser and using P180 abrasive paper;
- in most of the tested samples the surface roughness parameters *Rz*, *Ra*, *Rq* decreased with increasing granularity of abrasive papers.

The experimental results demonstrate that adhesive joint strength greatly depends on the applied degreasing process. In addition, adhesive joint strength is affected by the granularity of abrasive paper used for the surface treatment, too.

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