EFFECT OF A TYPE OF EPOXY ADHESIVE ON THE SELECTED MECHANICAL PROPERTIES OF ADHESIVE JOINTS OF THE STEEL SHEETS

Wpływ rodzaju kleju epoksydowego na wybrane właściwości mechaniczne połączeń klejowych blach stalowych

Anna RUDAWSKA ORCID 0000-0003-3592-8047

DOI: 10.15199/160.2020.3.6

Abstract: The paper presents the issues related to determination of the strength of the adhesive joints of C45 steel sheets which were made using six types of epoxy adhesives. Epidian 5, Epidian 53 and Epidian 57 epoxy resins and two types of curing agents: polyamide (PAC) and amine (Z-1) were used to prepare the epoxy adhesives compounds. The adhesive joints were subjected to strength tests in accordance with DIN EN 1465. When comparing the results of the shear strength tests of single-lap adhesive joints of C45 steel sheet prepared with the use of the analyzed adhesives, it was noticed that better results were obtained with the use of the adhesive compounds containing the PAC curing agent.
Keywords: adhesive compounds, epoxy resin, curing agent , adhesive joint, strength

Streszczenie: W artykule przedstawiono zagadnienia związane z określeniem wytrzymałości połączeń klejowych blachy ze stali C45 wykonanych za pomocą 6 wariantów kompozycji epoksydowych. Do wykonania klejów zastosowano trzy rodzaje żywic epoksydowych: Epidina 5, Epidian 53 oraz Epidian 57 oraz dwa rodzaje utwardzaczy poliamidowy (PAC) oraz aminowy (Z-1). Połączenia klejowe poddano badaniom wytrzymałościowym zgodnie z normą DIN EN 1465. Porównując wyniki badań wytrzymałości na ścinanie jednozakładkowych połączeń klejowych blachy ze stali C45 przygotowanych za pomocą analizowanych klejów zauważono, że lepsze efekty uzyskano przy wykorzystaniu kompozycji klejowej zawierającej utwardzacz PAC.
Słowa kluczowe: kompozycja klejowa, żywica epoksydowa, utwardzacz, połączenie klejowe, wytrzymałość

Introduction

Adhesion is one of the more frequently employed methods in the contemporary industry for permanent joining of the elements in various constructions [1, 6, 8]. The adhesive joints may be found in most of the products with a different application, or in the machines and many constructions. If an adhesive is not used directly in the manufacturing stage or during assembling, it is employed during transport, storage or packing of the products. The frequent application of adhesive joints is affected by their advantages and characteristic properties of adhesives, including, *inter alia*, a relative easiness of performing the joints, including also dissimilar ones, and, at the same time, high resistance [2, 4 ,6]. Many different materials may be glued with different thickness may be joined using the adhesives. The discussed method of linking the elements does not cause corrosion and infringement of the structure continuity at the site of joining. Adhesion has also its defects, *inter alia* a difficult disassembling, harmfulness of chemical substances and sometimes, long time of binding of adhesive joint. The mentioned defects do not, however, disqualify the discussed method of joining in the industry; on the contrary, there is a universal application nowadays of the adhesive joints in different branches of the industry.

A high diversity of the ready-to-use adhesives, including also constructional ones and their components affects a quite wide choice of a defined type of adhesive for the specified applications. The available epoxy resins and their curing agents allow preparing the different adhesive compositions, depending on the required properties of the adhesives [3, 5, 9, 11, 13].

In the present paper, the attempt to determine the effect of a type of epoxy adhesives, containing various epoxy resins and various curing agents on the selected mechanical properties if adhesive joints of steel sheets was undertaken. The single – lap adhesive joints were subjected to shear strength tests and based upon the obtained results, the shear strength and elongation were determined.

Methodology

• The joined material

For performance of adhesive joints, the samples of the sheet of carbon, non-alloy steel C45 was used. It is the non-alloy steel of quality 1,0503 for heat improvement, according to PN-EN 10083-2 and its chemical composition is found in Tab. 1.

Table 1. Chemical composition of C45 steel according to EN 10083-2 [14]

Type of steel	Chemical composition [%]								
	C	Si	Mn	Cr	Ni	Mo	Cu	S	P
C45 (1.0503)	0,42-0,50	0,1-0,4	0,5-0,8	Max 0,3	Max 0,3	Max 0,1	Max 0,3	Max 0,04	Max 0,04

The samples used in the tests had a shape of rectangular prism with dimensions 100 x 25 x 2 mm.

• Epoxy adhesives

During the tests, 6 two-component epoxy adhesives, consisting of epoxy resin and curing agents were used; their composition and determination is found in Tab.2.

Three epoxy resins, including non-modified epoxy resin Epidian 5 and two modified epoxy resins: Epidian 53 and Epidian 57 as well as two types of curing agent: polyamide (PAC) and amine (Z-1) were used. The mentioned products are manufactured by CIECH Sarzyna in Nowa Sarzyna (Poland).

The proportions of the mixture: resin and curing agent resulted from the stechiometric ratio, depending on the type of resin and curing agents [7].

Table 1. Chemical composition of C45 steel according to EN 10083-2 [14]

Type of resin	Type of curing agents	Weight ratio resin/ curing agents	Name of adhesive
Epidian 5	PAC	100:80	Epidian 5/PAC/100:80
Epidian 53			Epidian 53/PAC/100:80
Epidian 57			Epidian 57/PAC/100:80
Epidian 5	Z-1	100:10	Epidian 5/Z-1/100:10
Epidian 53			Epidian 53/Z-1/100:10
Epidian 57			Epidian 57/Z-1/100:10

• Shape and dimensions of adhesive joints

For strength tests, the single-lap adhesive joints with the dimensions shown in Fig.1 and Tab. 3 were prepared.

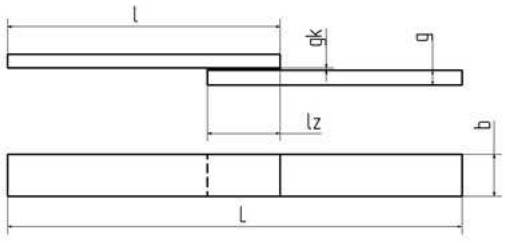

Fig. 1. The single-lap bonded joint

Table 3. The adhesive joints dimensions

Determination of dimension	l [mm]	b [mm]	g [mm]	L [mm]	lz [mm]	gk [mm]
Dimension	100	25	2	182	18	0,1

The length of the lap of adhesive joint was calculated from the formula for the limit length of lap joint, as presented in the work [6] and its value equal to 18 mm was adopted.

• The method of preparing the adhesive joints

The process for preparation of the surface of the steel sheet samples before adhesion covered 3 stages. The first stage consisted in a single degreasing of the surface of steel sheets with the use of acetone, by the rubbing method. After 2 minutes, the second stage of the surface preparation in a form of mechanical treatment was implemented. It was a manual abrasive dry treatment, using abrasive paper, made from corundum with granulation 320; during the mentioned treatment, 30 circulatory movements were carried out with the aim to obtain non-oriented structure. Then, the third stage of the surface preparation included the repeated degreasing, using acetone. The degreasing was performed three times, and after the last application of the degreasing agent the surfaces of the samples were left for 3 minutes to dry. The prepared samples were subjected to bonding, after the previous preparation of adhesive compositions.

For bonding of the samples, made from the steel sheets, the adhesive compositions consisting of epoxy resin and curing agent were used. The types of the employed components of the adhesives and their proportions, according to which the adhesives were prepared, are given in Tab. 2. The components of the particular adhesive compositions were measured on a balance of type TP-2/1 (FAWAG S.A., Lublin). The particular components were measured in a polymer container and then, mixed using a disc agitator at the stand for mixing of adhesives. The time of agitation was equal to 2 minutes and the time of removal of gas bubbles was also 2 minutes and the mentioned stage was implemented using a vacuum pump.

The particular adhesive compositions were evenly placed on the surface of one of the bonded samples using a special polymer spatula on the length of the anticipated lap of the adhesive joint. Then, the samples, creating the lap joint were fixed and the appropriate pressure was exerted on the bonded samples using weight of 1,5 kg. The mentioned operations were carried out in a special device where 6 samples were simultaneously tested. Then, the process of single-stage hardening on cold was carried out during 7 days. The process of adhesive preparation and surface preparation and other operations connected with the performance of adhesive joint as well as the hardening process were implemented at the ambient temperature of 22±2°C and the air humidity of 23±1%.

After the hardening process, the weight load was removed and 6 groups of adhesive joints, differing in the type of the employed adhesive composition, were created. In each group, 6 adhesive joints were performed.

• Types of the tests

During the experiment, the tests connected with the determination of the basic parameters of roughness of the surfaces of the bonded sheets and the strength tests of the adhesive joints of the steel sheets were carried out.

The measurements of the roughness parameters of the surface of the samples subjected to binding were conducted in HOMMEL – ETAMIC TURBO WAVE V.7.55 according to ISO Standard 25178.

The performed adhesive joints were subjected to strength tests according to standard DIN EN 1465 at the speed of the test equal to 5 mm/min in the strength machine. During the performance of the tests, the samples were fixed in the screw-wedge holders and were subjected to the shear strength test until the moment of destruction of the joint.

The results of the tests

• Characteristics of the surface of the bonded sheets

Tab. 4 presents the selected roughness parameters of the surfaces of the bonded sheets after the employed method of the preparation of their surface, as being described in the subsection “The method of preparing the adhesive joints”, together with their mean value. The tests covered 3 samples; each of them was subjected to 8 measurements of the selected parameters. Fig. 2 illustrates the example of a profile of roughness of the sample surface after the process of the preparation of the surface.

Table 4. Surface roughness parameters of adherends

Parameter	Surface roughness parameters, mm								
	Rt	Ra	Rq	Rsk	Rz	Rp	Rmax	RSm	Rku
Value (mean)	6,87	1,11	1,34	-0,29	5,16	2,23	6,77	0,22	2,48

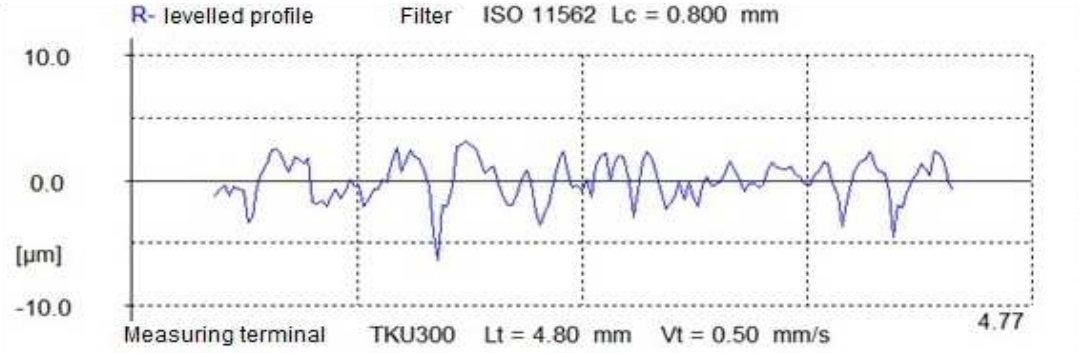

Fig. 2. An exemplary surface roughness profile for a sample prepared for bonding

The exemplary surface roughness profile of the sample after the employed method of preparing the surface allows a partial visualization of the state of roughness of the sample surface which was then subjected to the bonding process. Certain differences of the surface roughness profile in particular sites of the sample surface were observed what is characteristic of the manual treatment.

• The results of the strength tests

The presentation of the shear strength tests of the adhesive joints of steel sheets, being performed when using different adhesive combinations is given in Fig.3. in the tests, 6 variants of adhesive joints were used.

From the above presentation of the results it is followed that the adhesive joints performed with the epoxy adhesive compound, containing curing agents PAC, are characterized by considerably higher strength as compared to the joints made with the use of compounds, containing curing agent Z-1. The shear strength of the adhesive joints where curing agent PAC was employed, reaches the maximum value of 14.93 MPa whereas in the case of the adhesive joints made with the compound, containing curing agent Z-1, the maximum value of shear strength is equal to 4.60 MPa. It means that the adhesive joints performed with the application of curing agents PAC reveal 3-times higher shear strength in comparison with the adhesive joints made with the compound, containing curing agent Z-1, irrespectively of the epoxy resin. We may therefore, observe and confirm the results of the earlier studies [10, 11, 12] showing that the type of the hardener in the adhesive joints plays a significant role although the type of the employed epoxy resin is also important.

When comparing the results of the shear strength of the adhesive joints of the steel sheet, performed with the use of adhesive compounds containing polyamide hardener, we may state as follows:

- The highest shear strength was obtained in the case of the adhesive joints, made with the use of Epidian 53/PAC/100:80 (14.93 MPa) whereas the lowest value, equal to 10.33 MPa was obtained in the case of the adhesive joints performed with the use of epoxy resin Epidian 57 and curing agents PAC;

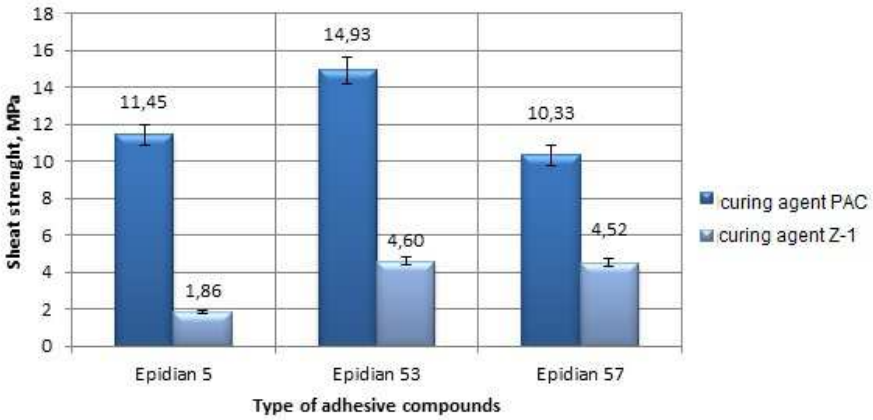

Fig. 3. Shear strength of adhesive joints of steel sheets, made with various epoxy adhesive compounds

- Value of the strength of the adhesive joints, made with the application of the compound consisting of epoxy resin Epidian 57 and curing agent PAC constitutes 90.2% of the value of strength of the adhesive joints performed with the combination of Epidian 5/PAC/100:80 and 69.2% of the value of the adhesive joints made with the use of adhesive compound Epidian 53/PAC/100:80.

When analyzing the results shown in Fig. 3 in relation to the shear resistance of the adhesive joints of the steel sheets, performed with the adhesive compounds, containing amine hardener, we may state as follows:

- The adhesive bonds performed with the use of compounds, containing epoxy resins Epidian 53 and Epidian 57, curing agents with the curing agent Z-1, reveal similar values of the shear strength. The strength of the compound Epidian 53/Z-1/100:10 is 4.60 MPa whereas that one of the compound Epidian 57/Z-1/100:10 is 4,52MPa;
- The lowest value of shear strength is equal to 1,86 and is assigned to the adhesive bonds which were performed using adhesive compound, containing epoxy resin Epidian 5;
- Value of the shear strength of the adhesive joints, made with the use of Epidian 5 and curing agent Z-1 constitutes 41,2% of the value of the strength of the adhesive joints, performed with the use of Epidian 57/Z-1/100:10 and 40,4% of the strength of the adhesive joints connected with the application of Epidian 53/Z-1/100:10.

When comparing the particular results and adopting the type of epoxy resin as a comparative criterion, we may observe the following:

- Strength of the adhesive bonds, performed with the use of compounds, containing epoxy resin Epidian 5 and hardener Z-1 is equal to 16,2% of the strength of the adhesive joints, prepared with the application of Epidian 5/PAC/100:80;
- The strength of the adhesive joints, made with the use of Epidian 53/PAC/100:80 is by ca. 70% higher than that one of the joints, performed with the compounds, containing epoxy resin Epidian 53 and curing agents Z-1;
- The strength of the adhesive joints for performance of which the compounds containing epoxy resin Epidian 57 and curing agent Z-1 were used, constitutes 43,8% of the strength of the adhesive joints prepared with the application of Epidian 57/PAC/100:80.

Fig. 4 illustrates the results of the elongation of the adhesive joints, obtained during the destruction tests of the samples of the joints, connected with the particular adhesive compounds (marking of the adhesive compounds on the diagram was presented in a simplified way, omitting the proportions of the constituents of the discussed compounds due to the readability of the diagram).

When analyzing the above discussed results, we may state that the adhesive joints, performed with the application of the epoxy adhesive compound, containing polyamide curing agents (PAC) reveal higher values of elongation in comparison with the bonds where the elements were linked with two-component adhesive and thre-ethylenoamine (Z-1) was the curing agent. Moreover, it is independent on the type of the employed epoxy resin. It means that the compounds, containing the polyamide curing agents (in relation to the analyzed epoxy resins ans the specified stechiometric relationships) are more

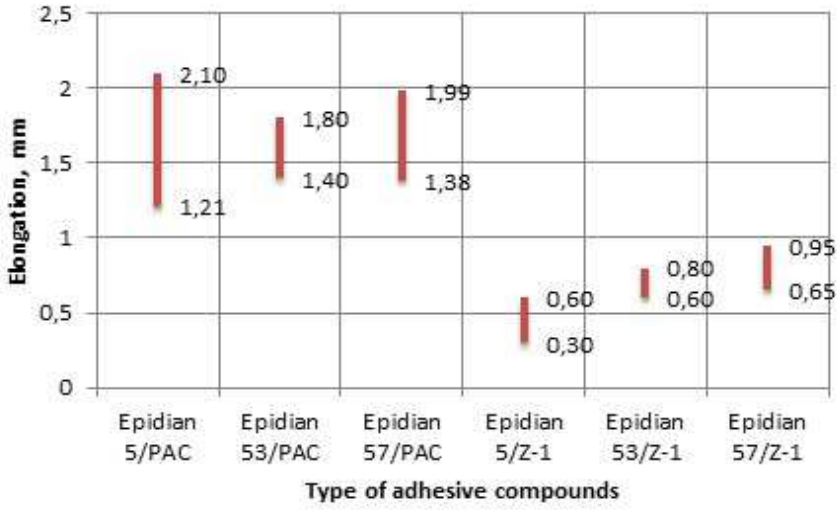

Fig. 4. Elongation at break of adhesive joints of steel sheets, made with various epoxy adhesive compounds

flexible in the adhesive joints as compared to the compounds, containing amine curing agent.

Summing up and conclusions

After conducting the comparative analysis of the results of the experimental tests, we may formulate the following conclusions:

- The adhesive bonds, being prepared with the epoxy adhesive compounds, containing curing agents PAC reveal considerably higher shear strength in comparison to the joints which were made with the epoxy adhesive compounds, containing curing agents Z-1;
- The adhesive joints in which there were used the adhesives containing curing agent PAC as well as curing agent Z-1 and the epoxy resin Epidian 53, are characterized by a higher strength in comparison to the adhesive joints , performed with the compounds containing epoxy resins Epidian 5 and Epidian 57,
- The application of curing agents PAC in the adhesive compounds with the epoxy resins cause generation of more flexible (elastic) joint than in the case of the application of curing agent Z-1.

When summing up the implemented experimental studies, we may reveal and confirm that the appropriate choice of the adhesive compounds affects significantly the strength of the adhesive joint. The precision of performing the operations during bonding process during the preparation of the surface to bonding as well as the appropriate quantity and type of the components of the adhesive compounds and its even distribution on the surface to be linked are also very important. They are the factors which may affect the strength of the adhesive joints.

The conducted tests showed that the application of the compounds, containing curing agents PAC enabled obtaining the adhesive joints of the C45 steel sheets with a higher strength than the application of the compounds with the content of curing agent Z-1.

References

[1] Brockmann W., Geiß P.L., Klingen J., Schröder B. 2009. Adhesive bonding. Materials, Applications and Technology. Weinheim, Germany: Wiley-Vch Press.

[2] Czaplicki J., Ćwikliński J., Godzimirski J., Konar P. 1987. Klejenie tworzyw konstrukcyjnych. Warszawa: WKŁ.

[3] Czub P., Bończa-Tomaszewski Z., Penczek P., Pielichowski J. 2002. Chemia i technologia żywic epoksydowych. Warszawa: WNT.

[4] da Silva L.F.M., Adams R.D. 2007. „Adhesive joint at high and low temperatures using similar and dissimilar adherends and dual adhesives". International Journal of Adhesion and Adhesives (27): 216–226.

[5] Fitton M.D., Broughton J.G. 2005. „Variable modulus adhesives: an approach to optimized joint performance". International Journal of Adhesion and Adhesives (25): 329–336.

[6] Godzimirski J., Kozakiewicz J., Łunarski J., Zielecki W. 1997. Konstrukcyjne połączenia klejowe elementów metalowych w budowie maszyn. Rzeszów: Oficyna Wydawnicza Politechniki Rzeszowskiej.

[7] Katalog: Epidian: żywice i utwardzacze, https://ciechresins.com [access: 01.10.2019].

[8] Kuczmaszewski J. 2006. Fundamentals of metal-metal adhesive joint design. Lublin: Politechnika Lubelska, Oddział PAN w Lublinie.

[9] Prolongo S.G., del Rosario G., Ureña A. 2006. „Comparative study on the adhesive properties of different epoxy resins". International Journal of Adhesion and Adhesives (26): 125 – 132.

[10] Rudawska A. 2005. „Dobór rodzaju kleju w aspekcie wytrzymałości połączeń klejowych blach ocynkowanych". Technologia i Automatyzacja Montażu (1): 28-29.

[11] Rudawska A., Cimek E. 2011. „Wpływ rodzaju kleju na wytrzymałość połączeń klejowych poliamidu PA6". Przetwórstwo Tworzyw 17(3): 198–202.

[12] Rudawska A., Kowalska B., Kubicki P. 2015. „Wytrzymałość połączeń klejowych polimerów, wykonanych za pomocą wybranych klejów sztywnych i elastycznych". Przetwórstwo Tworzyw 21(4): 343-348.

[13] Rudawska A., Kuczmaszewski J. 2012. „Badania porównawcze efektów modyfikacji żywic epoksydowych napełniaczami o dużym stopniu rozdrobnienia dla wybranych utwardzaczy". Przetwórstwo Tworzyw 18(5): 500–504.

[14] https://www.kronosedm.pl/stal-stal-c45-1-0503 [access: 01.10.2019].

Anna Rudawska, Ph.D., D.Sc., Eng.,
Associate Professor, Lublin University of Technology,
Faculty of Mechanical Engineering, the Chair of Production Engineering Rudiments
ul. Nadbystrzycka 36, 20-618 Lublin, Poland
e-mail: a.rudawska@pollub.pl