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Original Research

ANALYSIS OF THE STRENGTH OF ASSEMBLY JOINTS – WELDED JOINTS OF VARIOUS CONSTRUCTION MATERIALS

ANALIZA WYTRZYMAŁOŚCI POŁĄCZEŃ MONTAŻOWYCH – POŁĄCZEŃ SPAWANYCH RÓŻNYCH MATERIAŁÓW KONSTRUKCYJNYCH

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Abstract

The aim of the article was to present issues related to the strength analysis of one of the types of assembly joints - welded joints, taking into account the influence of selected factors: technological - welding method, construction - type of joints and material - type of joined material. The following welding methods were used (in accordance with the PN-EN ISO 4063 standard): arc welding in the shield of inert/active gases MIG/MAG (131/135), manual metal arc welding with a coated electrode MMA (111) and gas welding (oxyacetylene welding) (311).Butt joints and lap joints were made of CuZn37 copper alloy (PN-EN 1652), S235JR unalloyed structural steel (EN 10025) and 1.4301 acid-resistant steel (EN 10088). Welded joints samples were made with appropriate parameters, according to the welding methods. Strength tests of welded joints on MTS BIONIX 370.02 testing machine, in accordance with the PN-EN 1465 standard were provided. Based on the obtained test results, it can be seen that the value of stresses is affected by both the welding method and the type of joint structure, while the type of material to be welded should also be taken into account.

Keywords: welded joint, welding method, strength

Streszczenie

Celem artykułu było przedstawienie zagadnień związanych z analizą wytrzymałościową jednych z rodzajów połączeń montażowych – połączeń spawanych z uwzględnieniem wpływu wybranych czynników: technologicznych – metody spawania, konstrukcyjnych – rodzaju połączenia oraz materiałowych – rodzaju łączonego materiału. Zastosowano następujące metody spawania (zgodnie z normą PN-EN ISO 4063): spawanie łukowe elektrodą metalową w osłonie gazów obojętnych/aktywnych MIG/MAG (131/1355), spawanie łukowe elektrodą otuloną MMA (111) oraz spawanie gazowe acetylenowo-tlenowe (311). Wykonano połączenia doczołowe i zakładkowe stopu miedzi CuZn37 (PN-EN 1652) oraz stal niestopowa konstrukcyjna S235JR (EN 10025) oraz stal kwasoodporna 1.4301 (EN 10088). Próbki spawane wykonano przy odpowiednich parametrach, stosownie do metody spawania. Badania wytrzymałościowe połączeń spawanych przeprowadzono na maszynie wytrzymałościowej MTS BIONIX 370.02, zgodnie z normą PN-EN 1465. Na podstawie uzyskanych wyników badań można zauważyć, że na wartość naprężeń ma wpływ zarówno metoda spawania, jak i rodzaj konstrukcji połączenia, przy czym należy uwzględnić także rodzaj spawanego materiału.

Słowa kluczowe: połączenie spawane, metoda spawania, wytrzymałość

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1. Introduction

Joining is one of the most common technological processes in the engineering industry. In the technology of the assembly process in almost all industries, the type of assembly joints plays a very important role (Ferenc, 2007; Mistur & Czuchryj, 2005; Siwek, 2002). Technological progress makes it possible to combine materials with different properties, which is why various assembly joints are used in the assembly process, both permanent and temporary. The permanent joints include joining materials by welding, soldering and bonding (Ferenc, 2007; Mistur & Czuchryj, 2005; Siwek, 2002). These processes differ in the state of aggregation of the base materials and the binder at the point of joints, the type of bonds formed between the joined material and the binder, and the type of thermal and/or mechanical energy provided to create the joint (Ferenc, 2007; Łabanowski, 2018; Siwek, 2002). Moreover, depending on the type of joints, they are characterized by specific features specific to the joining method and geometric features of the joints (Łabanowski, 2018). They often enable the creation of a joint of dissimilar materials (Ciechacki & Szykowny, 2011; Łabanowski, 2005).

One of the methods of making assembly joints that has been widely used is welding (Ferenc, 2007; Łabanowski, 2018; Mistur & Czuchryj, 2005; Siwek, 2002), and over the years the technology of making this type of joints has developed significantly along with the development of techniques and devices (Bucior et al., 2017; Frydrych et al., 2011; Kozak, 2012; Nur, 2010). The accuracy and strength of welded joints are influenced by many factors: technological, structural and material (Bucior et al., 2017; Frydrych et al., 2011; Łabanowski, 2005; Rudawska & Sosnowski, 2013; Rudawska et al., 2017). In order to improve the quality of the joints made, both welding methods and their parameters are subject to continuous research, also in the aspect of making welded joints in various environments (Frydrych, 2012; Frydrych et al., 2013).

The work focused on determining the stresses of welded joints of three types of construction materials: copper alloy sheets, unalloyed structural steel and acid-resistant steel (material factor) in two structural configurations: lap joints and butt joints (construction factor). These joints were made using three welding methods, i.e. MIG/MAG welding, manual metal arc welding and gas welding (technological factor). The comparative criterion was the failure force of the welded joints.

2. Materials and methods

2.1. Materials

Three types of materials used for structural elements of mining equipment were used in the tests: CuZn37 copper alloy (PN-EN 1652), S235JR unalloyed structural steel (EN 10027) and 1.4301 acid-resistant steel (EN 10088). Materials were used to make the welded joints, provided by one of the company dealing with the repair of industrial structures, using the welding methods presented in the work. Selected properties of the listed materials are listed in Table 1.

Table 1. Mechanical properties of welded materials

Properties	Type of material		
	CuZn37[1]	S235JR[2]	1.4301[3]
Minimum yield strength R_e, MPa	$R_{p0,2}$ 180	Re 235	Re 205
Tensile strength $R_{m,}$ MPa	300-370	360-510	515-700
Minimum elongation $A_{min,}$ %	48	18	45

[1] https://emetal.eu/mosiadz/mosiadz-ISO
[2] PN-EN 10027-1: 2007: Systemy oznaczania stali - Część 1: Znaki stali.
[3] https://stalespecjalne.com.pl

CuZn37 brass is the most popular two-component alloy susceptible to plastic processing. S235JR steel can be welded without restrictions, without subsequent heat treatment and without preheating (https://tenslab.pl). S235JR steel is not susceptible to cold cracking, regardless of thickness and information on cold cracking of selected steel grades is described in the works (Kozak, 2012; (Frydrych, 2012; Frydrych et al., 2013). 1.4301 acid-resistant steel is very well weldable. The welding process should be followed by solution annealing if the carbon content remains at the upper level (https://stalespecjalne.com.pl).

2.2. Geometric characteristics of welded joints

For the analysis, lap and butt welded joints of the three materials mentioned in point 2.1 were made. The diagram and dimensions of the joints are shown below in Fig. 1 and Fig. 2 and in Table 2.

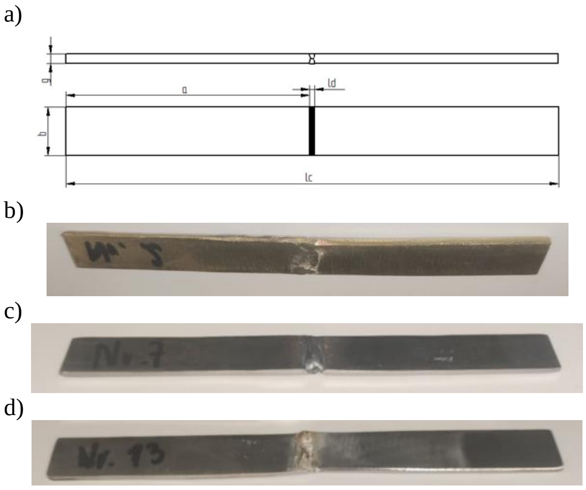

Fig. 1. Welded joints: a) diagram of butt welded joint used in the tests, b) made of copper alloy, c) made of unalloyed structural steel, d) made of acid-resistant steel

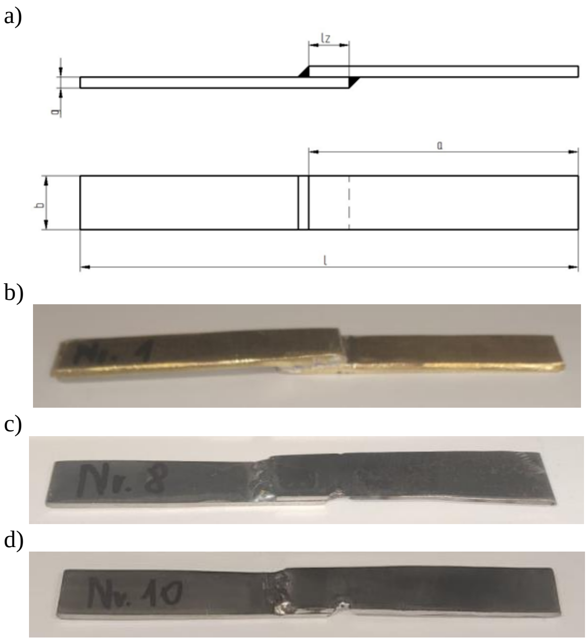

Fig. 2. Welded joints: a) diagram of the lap welded joint with double weld used in the tests, b) made of copper alloy, c) made of unalloyed structural steel, d) made of acid-resistant steel

Table 2. Mechanical properties of welded materials

Dimension designation	**a [mm]**	**b [mm]**	**g [mm]**	**l_c [mm]**	**l_d [mm]**
Joint type	butt welded joint				
Dimension	80	20	2	162	2
Dimension designation	**a [mm]**	**b [mm]**	**g [mm]**	**l [mm]**	**l_z [mm]**
Joint type	lap welded joint				
Dimension	80	20	2	140	20

2.3. Methods of preparing welded joints

Three methods were used to make the welded joints: the MIG/MAG method (131/135), MMA arc welding (111) and gas welding (311) (PN-EN ISO 4063). The welded joints samples were made manually by a welder with industrial experience and appropriate qualifications in the company's department dealing with the repair of industrial structures made of the materials presented in the work, using available equipment (Table 3).

When making welded joints, the following parameters of the welding process were used, listed in Table 3.

Table 3. Parameters of welding

Materials	**Method of welding/welding parameters**		
	MIG/MAG welding	Manual Metal Arc welding (MMA)	Gas welding
	131/135	111	311
1.4301 S235JR	- Migomat STEL MAX 503 IP54 ATX - gas: Ar 82%, CO_2 18% - wire: SG2, φ 1,2 mm - gas flow: 10 l/min - current intensity:150 A	- Migomat STEL MAX 503 IP54 ATX - Electrode BASEWELD 50E-7018, φ 2 mm x 350 mm (low-hydrogen covered electrode) - welding load voltage: 18 V	- oxyacetylene blowpipe - gas: technical oxygen, technical acetylene
CuZn37		-	

2.4. Tests

Three methods were used to make the welded joints: the MIG/MAG method (131/135), MMA arc welding (111) and gas welding (311) (PN-EN ISO 4063). The welded joints samples were made manually by a welder with industrial experience and appropriate qualifications in the company's department dealing with the repair of industrial structures made of the materials presented in the work, using available equipment (Table 3).

The welded joints were subjected to strength tests, in which the failure force of the welded joints was determined. Strength tests of welded joints on MTS BIONIX 370.02 testing machine, in accordance with the PN-EN 1465 standard were provided. Strength tests were carried out at a temperature of 23±1°C and air humidity of 34±1%. The tests were carried out until the welded joint sample cracked and the values of maximum stresses were given.

Strength tests were carried out on 5 joints made by the welding methods mentioned in point 2.3 for three materials. In the case of S235JR unalloyed structural steel and acid-resistant steel 1.4301, 3 series of 5 welded joints were made, a total of 15 welded joints for each type of material, and in the case of CuZn37 copper alloy, 2 series of welded joints, 5 joints each (the total of welded joints was 10).

3. Results

3.1. Strength test results

The results of strength tests of butt welded joints are shown in Fig. 3 and of lap welded joints in Fig. 4.

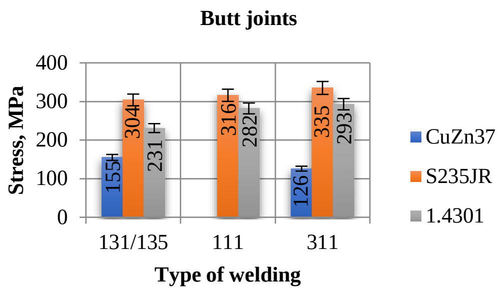

Fig. 3. Stress of butt welded joints

Based on the results summarized in Fig. 3, it can be seen that the highest stresses occurred in the case of butt welded joints of S235JR unalloyed structural steel, and this applies to each of the three welding methods used. The smallest stresses were shown by butt welded joints of CuZn37 copper alloy, with lower values obtained after using the gas welding method (126 MPa) than using the MIG/MAG welding method (155 MPa) by about 19%.

The difference in the stress value of butt welded joints of unalloyed structural steel (S235JR) and acid-resistant steel (1.4301) for individual joining methods is: method 135/136 - 24%, method 111 - 21% and the method 311 - 23%

Considering the welding method, both in the case of butt welded joints of unalloyed structural steel and acid-resistant steel, the highest stress values were obtained using the gas welding method (311).

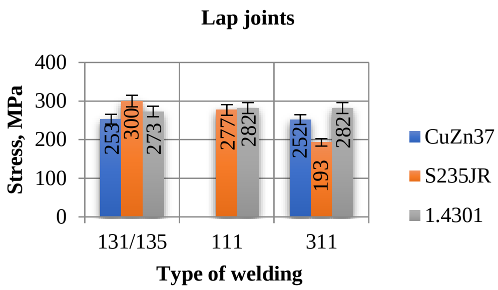

Fig. 4. Stress of lap welded joints

Based on the summarized results (Fig. 4), it can be seen that:

- in the case of lap welded joints of the copper alloy, no differences in stress values were observed (method 131/135 - 253 MPa and method 311 - 252 MPa),
- a similar relationship was observed in the case of acid-resistant steel for the 111 and 311 welding methods (282 MPa), while a lower stress value of welded joints was obtained after using the MIG/MAG method - 273 MPa, and this difference is insignificant and amounts to only about 3%,
- in the case of welded joints of unalloyed structural steel (S235JR), the highest stresses were obtained in the case of using the MIG/MAG welding method (300 MPa), while the lowest - for joints made using the gas method (193 MPa), the difference between these values is 36%.

3.2. Basic descriptive statistics

A basic descriptive statistics was presented in Table 4 and Table 5 and the tables were performed on the results from the strength test. Basic statistics is the basis for further analyzes and inferences.

Table 3. Parameters of descriptive statistics of butt welded joints stress [MPa]

Type of material	Basic descriptive statistics									
	No. of tests	Mean	Median	Mode	Mode size	Range	Variance	Standard deviation	Skewness	Kurtosis
	Welding method									
MIGMAG welding method (131/135)										
CuZn37	5	155	155	multiple	1	4	2.50	1.58	0.00	-1.20
S235JR	5	304	304	multiple	1	4	2.50	1.58	0.00	-1.20
1.4301	5	231	231	231	2	3	1.30	1.14	0.40	-0.18
MMA method (311)										
S235JR	5	316	316	317	2	4	2.80	1.67	-1.09	0.53
1.4301	5	282	282	283	2	3	1.70	1.30	-0.54	-1.49
gas welding method (311)										
CuZn37	5	126	125	125	2	4	2.30	1.52	1.12	1.46
S235JR	5	335	335	336	2	4	2.80	1.67	-1.09	0.54
1.4301	5	293	293	multiple	2	3	1.50	1.22	-1.36	2.00

Table 4. Parameters of descriptive statistics of lap welded joints stress [MPa]

Type of material	**Basic descriptive statistics**									
	No. of tests	Mean	Median	Mode	Mode size	Range	Variance	Standard deviation	Skewness	Kurtosis
	Welding method									
MIGMAG welding method (131/135)										
CuZn37	5	252	253	multiple	1	5	4.30	2.07	-0.24	-1.96
S235JR	5	300	300	302	2	4	3.20	1.79	-0.05	-2.32
1.4301	5	273	273	multiple	1	5	3.70	1.92	0.59	-0.02
MMA method (111)										
S235JR	5	277	277	277	2	3	1.30	1.14	0.40	-0.18
1.4301	5	282	282	283	2	3	1.70	1.30	-0.54	-1.49
gas welding method (311)										
CuZn37	5	252	252	multiple	2	3	1.50	1.22	-1.36	2.00
S235JR	5	193	193	multiple	1	5	4.30	2.07	-0.24	-1.96
1.4301	5	282	282	283	2	4,	2.80	1.67	-1.09	0.54

Comparing the type of material and type of construction of welded joints, the correlation coefficient r (X,Y) for the MIG/MAG method was +0.99, which means that regardless of the type of construction of the joint, a similar dependence of stress values was observed depending on the type of joined material. Higher stress values obtained for butt welded joints correspond to higher stress values of lap welded joints, regardless of the type of material. In the case of welded joints made by the MMA method (111), the Pearson correlation coefficient r was -1, which means that the higher strength of butt welded joints is accompanied by the lower strength of lap joints. However, when considering gas welded joints (311), the correlation coefficient was - 0.37, which means a rather weak relationship between the type of joints and the type of welded material.

3.3. Discussion of the results

Based on the results presented in Fig. 3 and Fig. 4, it was noticed that:

- considering the MIG/MAG method (131/135): (i) comparable stress values were obtained for butt joints and lap joints of unalloyed structural steel, which means that in the case of this steel, the type of joint structure will not affect the obtained stress values, (ii) in both structural cases of welded joints of both copper alloy and acid-resistant steel, differences in stress values depending on the type of joint were observed, with higher stress values obtained for lap joints,
- analyzing the MMA method (111): (i) in the case of welded joints made of acid-resistant steel, there are no differences in the stress values of butt joints and lap joints, (ii) considering the stress values of welded joints of unalloyed structural steel, the stress values were higher for butt joints by about 12% than for lap joints.
- considering the gas welding method (311): (i) in the case of copper alloy welded joints, significant differences in stress values obtained by butt joints (123 MPa) and lap joints (252 MPa) are observed, and this difference is 50%, (ii) welded joints of unalloyed structural steel are also characterized by significant differences in stress values depending on the structure, with a higher stress value for butt joints (335 MPa) than lap joints (193 MPa), and this difference is 42%,
- among all welded joints, the highest stress value was obtained for joints of unalloyed structural steel welded using the MIG/MAG method (335 MPa), and this value exceeded the minimum yield strength Re (235 MPa) and approached the lower limit of tensile strength, i.e. 360 MPa (Table 1), which means that after exceeding the yield point, a significant increase in plastic deformation occurs in the stretched material,
- in the case of butt welded copper alloy joints, the stress value (155 MPa – MIG/MAG method and 125 MPa – gas welding method) did not exceed the minimum yield strength, i.e. 180 MPa, while this value was exceeded in the case of lap joints, regardless of welding methods.

In the work (Rudawska et al., 2017) results of strength tests of butt and lap welded joints (with single and double welds) of S235JR steel made with the use of arc welding with a coated electrode. Based on the obtained results, it was noticed that the highest strength was obtained for butt welded joints. On the other hand, the highest transferred force and the highest value of elongation were achieved by lap welded joints with a double weld. In this article, too, greater strength is obtained for butt welded joints than for lap joints.

In addition to the indication in this work that the type of construction of joints and the type of welded material as well as the welding method affect the strength parameters of welded joints, other factors should also be taken into account when making welded joints. In the work (Bucior et al., 2017) it was indicated that an important element is also the surface treatment (especially of thin sheets) for the welding process.

4. Conclusions

Based on the obtained test results, it can be seen that the value of stresses and deformations is affected by both the welding method and the type of joint structure, while the type of material to be welded should also be taken into account. The literature confirmed that weldability is a material, technological and design feature at the same time.

- For copper alloy welded joints, the type of joint construction type is more important than the welding method, and lap joints are preferred for this material.
- In the case of welded joints of unalloyed structural steel, higher stress values were obtained for butt welded joints, regardless of the welding method.
- Considering the welded joints of acid-resistant steel, in most variants of both corruption and welding methods, similar values were obtained, only in the case of butt welded joints made using the MIG/MAG method, the stress value is noticeably lower than the others and amounts to 231 MPa.

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