The influence of the chosen welding technology on the microstructure and selected mechanical properties of welded magnesium alloy AZ91

Wpływ technologii spawania na mikrostrukturę i wybrane właściwości mechaniczne złączy spawanych stopu AZ91

Abstract

Magnesium alloys are a part of a group of lightweight alloys, which are important in practical use in constructions. The paper shows the results obtained by research into welded AZ91 magnesium alloy. Within the scope of research microstructure examination and tensile testing were done. Magnesium alloy was welded by two methods – 141 (TIG) and 522 (laser gas welding). The values of tensile strength of welded joints in majority cases were higher than values of tensile strength of the base material. The microstructure examination and chemical analysis made it possible to explain the phenomena occurring in the AZ91 during welding.

Keywords: AZ91 magnesium alloy; welding, mechanical properties; microstructure; welded joint

Streszczenie

Stopy magnezu należą do grupy stopów metali lekkich, używanych w konstrukcjach. W artykule przedstawiono wyniki uzyskane w czasie badań złączy spawanych stopu AZ91. Wykonane zostały: obserwacja mikrostruktury i próba jednoosiowego rozciągania. Złącza zostały wykonane metodą 141 (TIG) i 522 (spawanie laserem gazowym). Wartości wytrzymałości na rozciąganie złączy spawanych w większości przypadków były wyższe niż wartości tych wielkości w przypadku materiału rodzimego. Badania mikrostruktury i składu chemicznego pozwoliły wyjaśnić zjawiska zachodzące w stopie podczas spawania.

Słowa kluczowe: AZ92; stopy magnezu; spawanie; właściwości mechaniczne; mikrostruktura; złącze spawane

Introduction

Magnesium is one of the lightest metals [1] (density 1.74 g/cm³ – approximately fourfold lighter material than a steel [2]) of all practical engineering materials. Magnesium alloys have high specific strength, and exceptional mechanical properties in comparison to its low density. These properties are: high strength and high elasticity. In the recent years, magnesium alloys, due to their relatively low mass, have been of an increasingly big interest mostly to the automotive industry.

The basic methods used for welding the magnesium alloys are: 141 (TIG), 131 (MIG) and 52 (laser welding).

The adequate preparation of elements before welding is essential. Incorrectly cleaned ends can cause lack of fusion and anomalous wetting.

Difficulties with welding the magnesium alloys result from the following factors [3]:

– high chemical reactivity between magnesium and oxygen. Magnesium oxides which have melting point 2500°C, inhibit the welding process;
– high thermal conductivity;
– low melting point;
– the colour of material do not change during heating before welding;
– brittleness of a few magnesium alloys in temperature higher than 400°C;
– low tensile strength of few magnesium alloys in temperature higher than 500 °C;
– low temperature of evaporation of the magnesium (1090 °C);
– flammability of magnesium.

Alternating current and direct current with positive polarity can be used for welding in 141 method. Direct current with negative polarity should not be used because magnesium oxides cannot be removed from the surface of material [3].

Research methodology

Tensile testing

Tensile testing was realized in order to determine the tensile strength of the base material and the welded joints. Specimens were extracted from the base material

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and the joints welded by using both methods. Next they were prepared by machining. Three specimens of each type were used for testing. The technical drawing of sample is shown in Fig. 1 and Fig. 2.

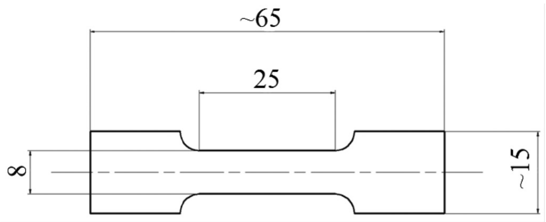

Fig. 1. The technical drawing of specimen for tensile testing cut from welded joints
Rys. 1. Schemat próbki do próby jednoosiowego rozciągania pobrana z materiału rodzimego

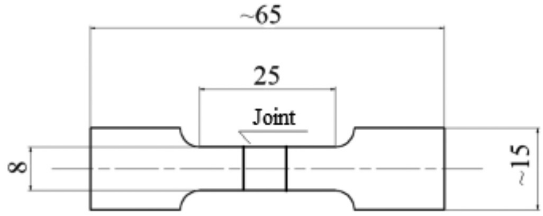

Fig. 2. The technical drawing of specimen for tensile testing cut from base material
Rys. 2. Schemat próbki do próby jednoosiowego rozciągania pobrana ze złączy spawanych

Microstructure examination

The fragments of welded joints were specimen used for microstructure examination. Extracted specimens was machined and prepared for the metallographic examination in the grinder-polisher produced by Struers. The silica colloidal was etching reagent used for revealing the microstructure of welded joints. The microstructure was observed using an MA-200 (light microscope) and NEXUS 400 (SEM).

Material

The fragments of casted magnesium alloy AZ91 were used as the base material. The chemical composition of AZ91 accordant with ASTM B93/B93M standard is given in Table 1.

The Mg – Al phase diagram is shown in Fig. 3. [4]

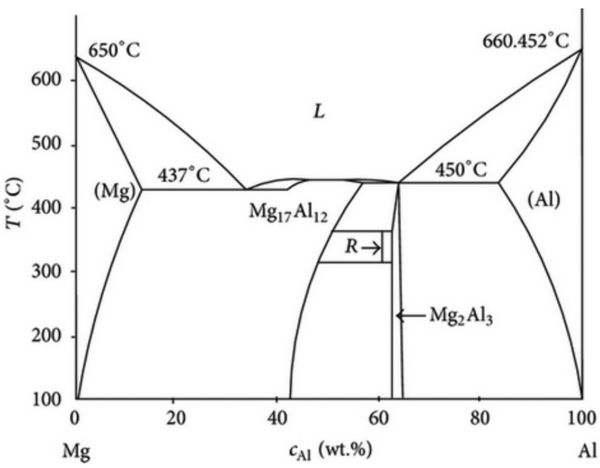

Fig. 3. The Mg – Al phase diagram
Rys. 3. Układ równowagi Mg-Al

Table I. The chemical composition of AZ91
Tablica I. Skład chemiczny stopu AZ91

Cast	Chemical composition [%]						
	Al	Zn	Mn	Si	Fe	CU	Ni
AZ91	8,5 – 9,5	0,45 – 0,9	0,15 – 0,4	0,08	0,004	0,025	0,001

The microstructure of AZ91 magnesium alloy is shown in Fig. 4 and Fig. 5.

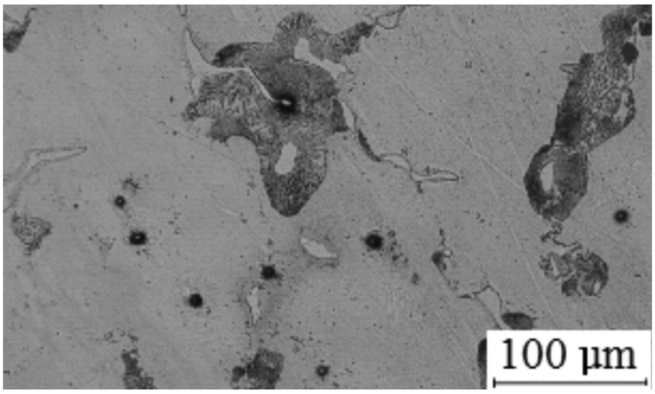

Fig. 4. The microstructure of the base material – AZ91 magnesium alloy
Rys. 4. Mikrostruktura materiału rodzimego – stop magnezu AZ91

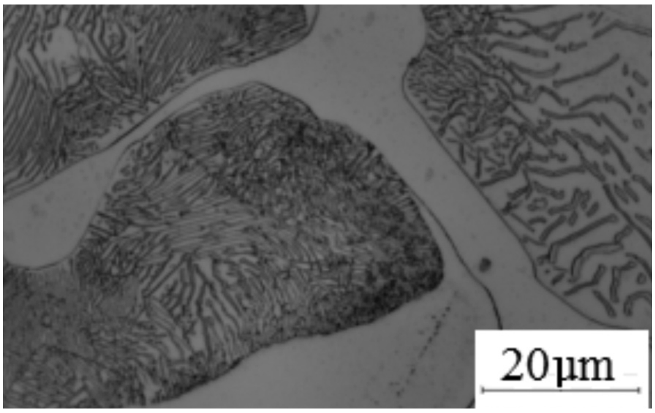

Fig. 5. The microstructure of the base material – AZ91 magnesium alloy
Rys. 5. Mikrostruktura materiału rodzimego – stop magnezu AZ91

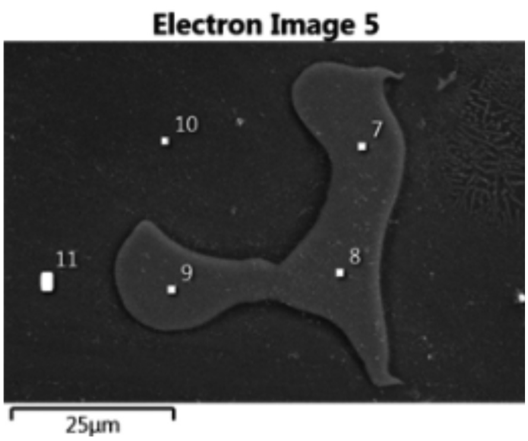

Fig. 6. The microstructure of base material with marked points of chemical analysis
Rys. 6. Mikrostruktura materiału rodzimego z zaznaczonymi punktami, w których wykonana została analiza chemiczna

The observed microstructure of base material was subjected to the chemical analysis and line scan. Chemical analysis was performed in points marked on the microstructure shown in Fig. 6.

The results of the chemical analysis are shown in Table 2.

Table II. The results of the chemical analysis
Tablica II. Wyniki analizy chemicznej

		Atomic %		
		Mg	**Al**	**Zn**
Number of point	7	62,67	35,67	1,65
	8	63,33	34,98	1,69
	9	62,90	35,65	1,45
	10	95,01	4,99	-
	11	92,02	7,91	-

The microstructure of base material and results of line scan are shown in Fig. 7.

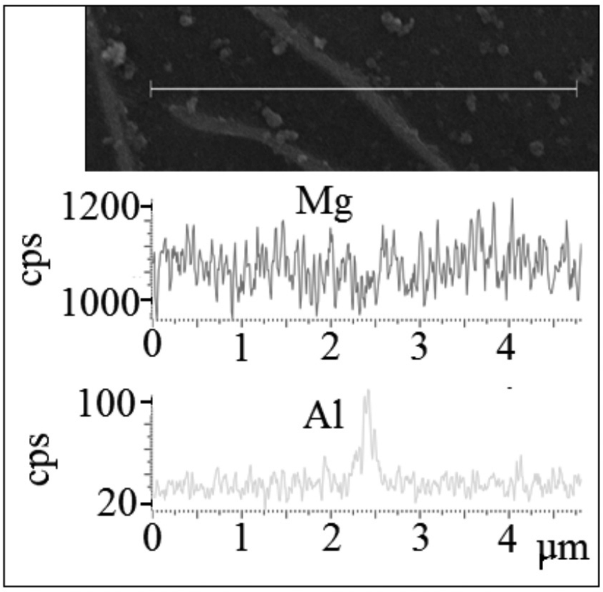

Fig. 7. The microstructure of base material and the results of line scan
Rys. 7. Mikrostruktura materiału rodzimego oraz wyniki analizy liniowej

Tensile test diagrams received in tensile testing of base material are shown in Fig. 8.

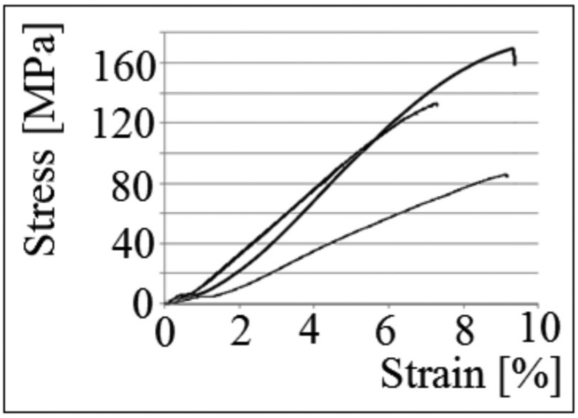

Fig. 8. The tensile test diagrams received in tensile testing
Rys. 8. Wykresy uzyskane w wyniku jednoosiowej próby rozciągania

Table III. The values of tensile strength of base material
Tablica III. Wartości wytrzymałości na rozciąganie materiału rodzimego uzyskane w wyniku próby jednoosiowego rozciągania

Base material			
Number of specimen	1	2	3
Rm [Mpa]	133	86	169

The filler material was extracted from the same magnesium alloy AZ91.

Preparation for welding

The 141 (TIG) and 522 (laser gas welding) methods were used for welding. The parts prepared for welding by 141 method are shown in Fig. 9.

The parts prepared for welding by 522 method are shown in Fig. 10.

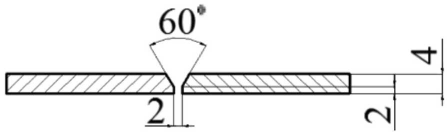

Fig. 9. The parts prepared for TIG welding
Rys. 9. Brzegi materiału rodzimego przygotowane do spawania TIG

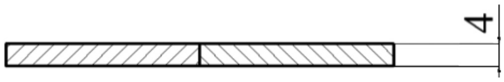

Fig. 10. The parts prepared for laser gas welding
Rys. 10. Brzegi materiału rodzimego przygotowane do spawania laserowego

WPS was written during the period of preparing to welding. The selected parameters of welding are shown in Table 4 (141 method) and Table 5 (522 method).

Table IV. The selected parameters of TIG welding
Tablica IV. Wybrane parametry spawania TIG

Polarity	DC, (+)
Amperage	30 A
Welding travel speed	0,05 m/min
Shielding gas type	Argon
Preheat temperature	200 ˚C
Interpass temperature	200 - 300 ˚C
Filler	AZ91

Table V. The selected parametrs od laser gas welding
Tablica V. Wybrane parametry spawania laserowego

Power	2 kW
Welding travel speed	3 m/min
Shielding gas type	Helium
Preheating temperature	Parts was not preheated
Filler	Welding without filler

Welded joints

Laser gas welding (522)
The macrostructure of joint welded by 522 method is shown in Fig. 11.

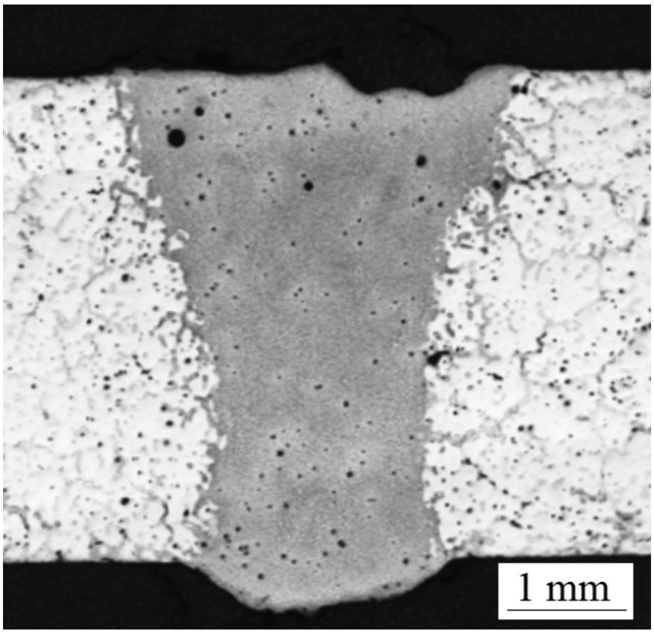

Fig. 11. The macrostructure of joint welded by 522 method
Rys. 11. Makrostruktura złącza spawanego metodą 522

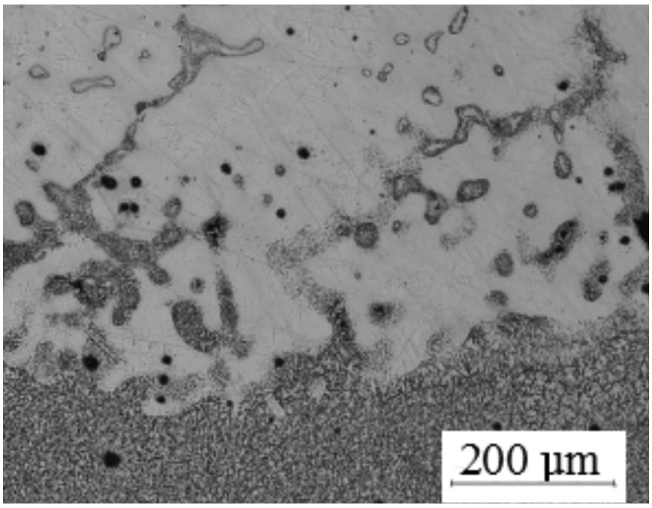

Fig. 12. The line of fusion
Rys. 12. Linia wtopienia

The microstructure of joint is shown in Fig. 13 and Fig. 14.

The microstructure in the line of fusion was subjected to the chemical analysis. The chemical analysis was performed in points marked on the microstructure shown in Fig. 15.

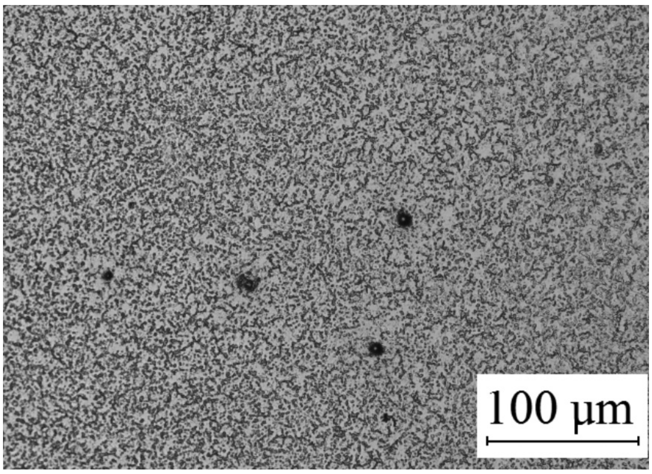

Fig. 13. The microstructure of the joint
Rys. 13. Mikrostruktura spoiny

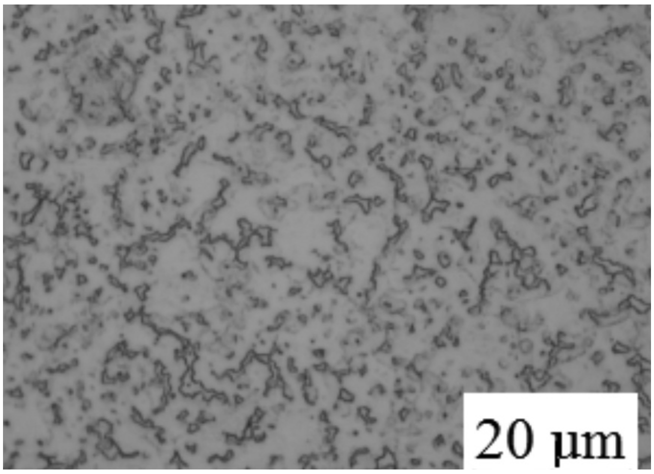

Fig. 14. The microstructure of the joint
Rys. 14. Mikrostruktura spoiny

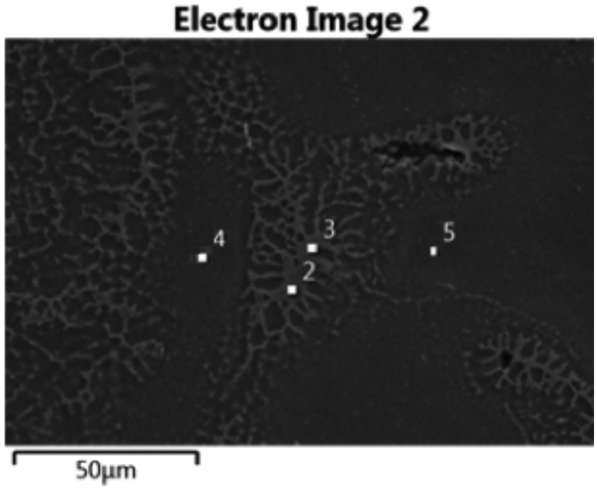

Fig. 15. The microstructure of line of fusion with marked points of chemical analysis
Rys. 15. Mikrostruktura linii wtopienia z zaznaczonymi punktami, w których wykonywana była analiza chemiczna

The outcome of the chemical analysis are shown in Table 6.

Tensile test diagrams received by tensile testing of connection welded by 522 method are shown in Fig. 16.

Table VI. The results of the chemical analysis
Tablica VI. Wyniki analizy chemicznej

		Atomic %		
		Mg	**Al**	**Zn**
Number of point	2	68,4	30,21	1,39
	3	69,56	29,14	1,30
	4	94,66	5,34	-
	5	94,65	5,35	-

Table VII. The values of tensile strength of specimens from joint welded by 522 method
Tablica VII. Wartości wytrzymałości na rozciąganie próbek ze złącza spawanego metodą 522

Joint welded by 522 method			
Number of specimen	1	2	3
Rm [Mpa]	135	135	138

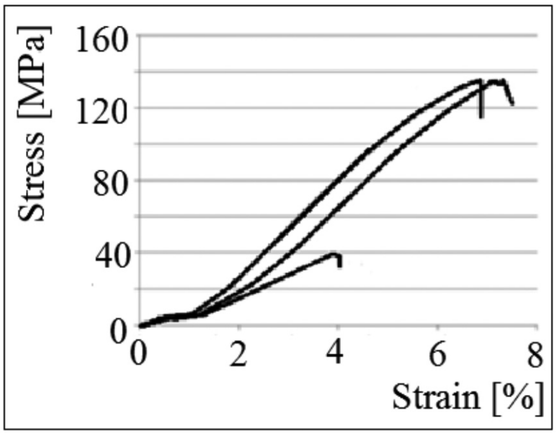

Fig. 16. Tensile test diagrams received by tensile testing of connection welded by 522 method.
Rys. 16. Wartości wytrzymałości na rozciąganie uzyskane w wyniku próby jednoosiowego rozciągania złącza spawanego metodą 522

The values of tensile strength of tested specimens are shown in Table 7.

TIG (141)

The macrostructure of joint welded by 141 method is shown in Fig. 17.
The microstructure of joint is shown in Fig. 18 and Fig. 19.

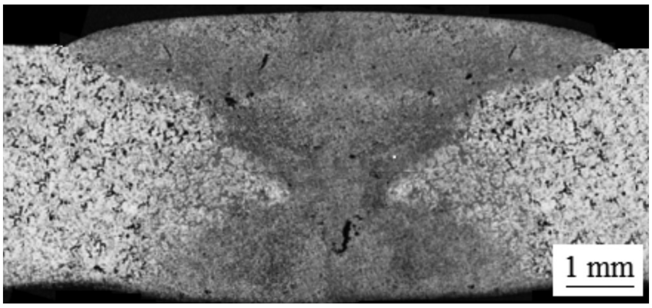

Fig. 17. The macrostructure of joint welded by 141 method
Rys. 17. Makrostruktura złącza spawanego metodą 141

Table VIII. The values of tensile strength of specimens from joint welded by 141 method
Tablica VIII. Wartości wytrzymałości na rozciąganie próbek ze złącza spawanego metodą 141

Joint welded by 141 method			
Number of specimen	1	2	3
Rm [Mpa]	146	137	104

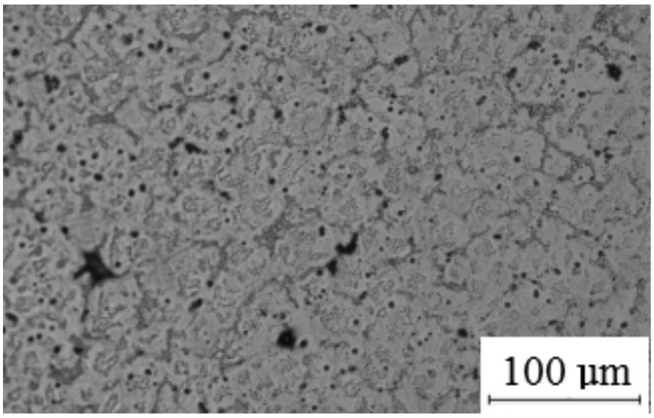

Fig. 18. The microstructure of joint welded by 141 method
Rys. 18. Mikrostruktura spoiny

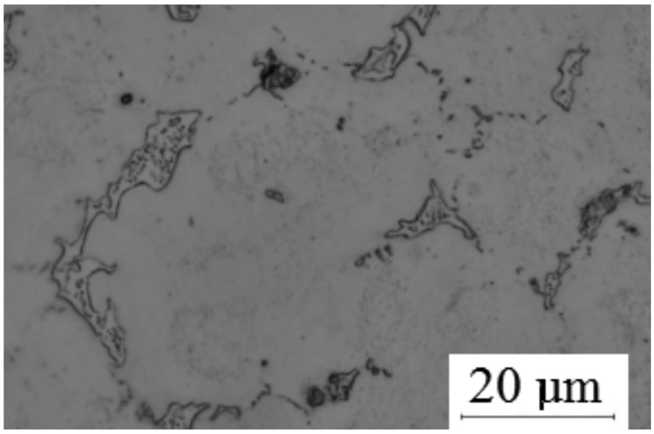

Fig. 19. The microstructure of joint
Rys. 19. Mikrostruktura spoiny

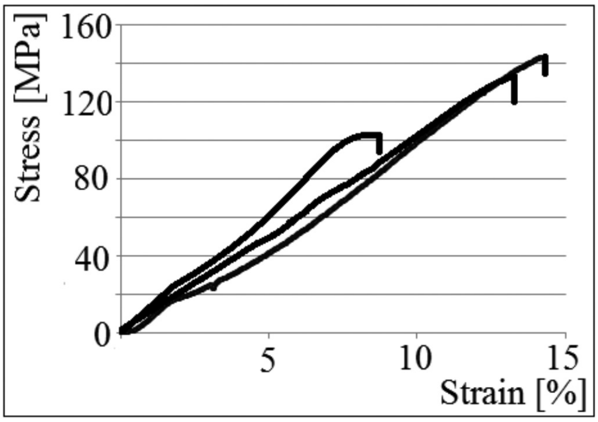

Fig. 20. Tensile test diagrams received by tensile testing of connection welded by 141 method
Rys. 20. Wartości wytrzymałości na rozciąganie uzyskane w wyniku próby jednoosiowego rozciągania złącza spawanego metodą 141

Discussion and conclusions

The phase, solid solution aluminum-magnesium and alternately arranged precipitations of solid solution aluminum-magnesium are observed in the microstructure of the base material [5]. The morphology and chemical composition of observed microstructure confirm that.

The microstructural changes were not observed in the base material adjacent to joint. Magnesium alloy AZ91 should be heated several dozen hours in 420˚C to alter the microstructure [5]. The approximate time of influence of that temperature in the base material close to joint during welding process was several minutes. The time is not sufficient to draw the microstructural changes in this type of magnesium alloy.

Tensile test pieces which were extracted from welded joints which were fractured in the base material in majority of cases. It proves that the joint has the higher tensile strength than the base material. The crystals in joints are small and they have fewer impairments than conventional cast. The secondary microstructure which is related to phase transitions is presents in joints. It has positive effect on the mechanical properties of welding connection.

The scattered welding imperfections caused the fracturing in the joint of only one specimen welded by 141 and one welded by 522.

The single gas inclusions in the joints occur because of gases dissolved in liquid metal and their emission. Solubility of gases in liquid metal decline when the temperature lowers. Emitted gases have not enough time to leave the joint because the decrease of temperature during the welding process is sharp. Gases stay in the joint and make the gas inclusions [3].

The zone of fusion is more concentrated in case of the 522 welding method due to the focused laser beam and the high intensity of process. This intensity has also effect on dispersion of the eutectic which is observed in the joint. In case of the 522 method dispersion is much higher than in case of the 141 method.

Eutectic which include solid solution aluminium-magnesium and phase   is observed in the microstructure of joint. It is confirmed by the morphology and the chemical composition of microstructure of joint.

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