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SUSCEPTIBILITY TESTING FOR WELDING OF AlMg ALLOYS INTENDED FOR EXTRUSION

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The objective of research was to determine the weldability, using Tungsten Inert Gas (TIG) of extruded sections made of hard-deformable 5xxx series aluminum alloys with differing magnesium content, i.e. AlMg3, AlMg4,5, AlMg5, AlMg7. Welded joints were obtained as a result of a welding process consisting of several steps. Only welds characterized by very good appearance and quality were selected for tests. As a result of conducted research, TIG welding parameters were determined for sections with a thickness of 8 mm. It was observed that alloys of differing Mg content are characterized by high weldability and do not exhibit a significant reduction of the yield point. Moreover, joints exhibit uniform hardness distribution in the welded joint and heat-affected zone. Tensile strength is reduced.

Key words: TIG welding, AlMg alloys, parameters of welding, tensile strength, hardness HV01

INTRODUCTION

Aluminum alloys, as lightweight materials, are an excellent alternative to steel in many areas of industry. However, the low strength of aluminum alloys limits the extent of their application in industry [1]. This is why research is being conducted on new aluminum alloys with better mechanical properties in many research centers. Studies show that the addition of Mg in Al alloys leads to an increase in the strength of hot-formed AlMg alloys [2]. 7xxx series alloys, involving zinc, are among the aluminum alloys with the highest strength, but they have a lower resistance to corrosion than alloys in the 5xxx series. The interest in alloys from this series is mainly the result of their suitability for mechanical processing and welding as well as their resistance to corrosion, which is 2 - 3 times greater than that of 6xxx alloys, which are the most widespread [3].

Expansion of the applications of these alloys, particularly in the construction and shipbuilding industries, requires development of methods of joining them that will ensure high strength of joints. Welding of aluminum alloys was made difficult by problems related to oxide removal and strength reduction in the heat-affected zone. Nevertheless, new welding techniques are solving these problems [4]. Tungsten inert gas welding, or TIG welding, is arc welding using a non-consumable electrode shielded by a neutral gas, and it is the method most commonly used to manufacture structures made of aluminum sections [5].

One of the main problems during welding of aluminum and its alloys is its resulting porosity. Analysis of the gas found inside pores has shown that hydrogen is the main gas causing porosity. Dissolved gas (H_2) that cannot “escape” as the weld congeals forms voids and reduces the strength of the material in the weld and heat-affected zone [6-8].

5xxx series alloys have medium strength, and the highest mechanical properties dependent on magnesium content reach approx. 300 MPa and are comparable to high AlMgSi alloys [2]. In previous studies did not compare alloys with Mg content from 3 - 7,5 % for sections with thicknesses greater than 2 mm, which is why this problem was investigated in this article in order to determine welding capabilities and the change of mechanical properties related to this.

MATERIALS AND METHODS

Tests of the weldability of 5xxx series hard-deformable alloys were conducted by welding sections.

Sections were extruded at OML Skawina on a semi-industrial hydraulic press with a pressing force of 5 MN, equipped with a system for measuring the temperature of the metal leaving the die hole. Sections extruded from ingots with a diameter of approx. 100 mm, with four different chemical compositions, were tested. In order to investigate the influence of Mg content, alloys with Mg content from 3,5 to 7,14 % were selected (Table 1).

Welding of aluminum sections was performed by means of a robotic test station for tungsten inert gas welding (TIG) (Figure 1), in an argon gas shield. The station is equipped with: a welding robot from Panasonic (with a touch system for welding wire detection, maximum reach of 1 400 mm, and repeatability of motion ± 0,08 mm), the robot’s welding grip, 300 A TIG welding source, cold wire feeder, uniaxial positioner with a maximum load of 500 kg. An LNT AlMg4,5MnZr

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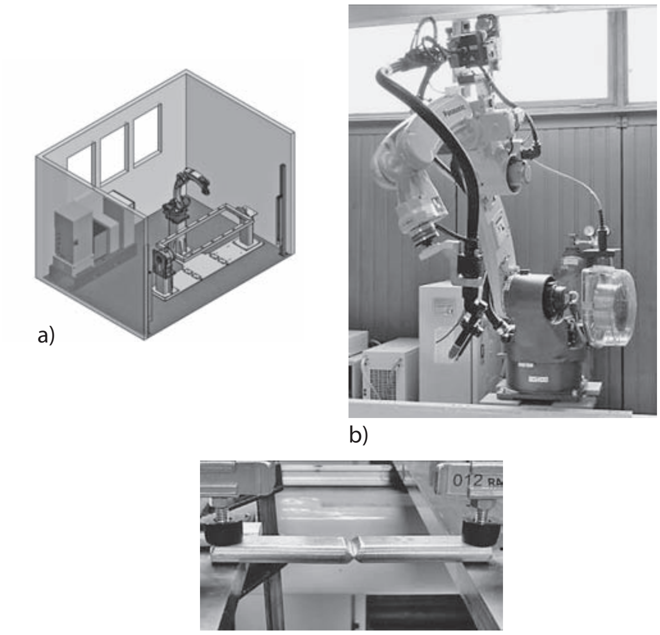
Table 1 **Chemical composition of extruded sections subjected to welding / wt. %**

	AlMg3	AlMg4,5	AlMg5	AlMg7
Si	0,224	0,229	0,246	0,235
Fe	0,140	0,145	0,146	0,097
Cu	0,007	0,004	0,004	0,004
Mn	0,465	0,553	0,567	0,580
Mg	3,44	4,44	5,54	7,14
Cr	0,002	0,120	0,002	0,149
Zn	0,002	0,024	0,026	0,026
Ti	0,018	0,018	0,019	0,019
Al	R	R	R	R

rod from the Lincoln Electric company, with a diameter of 2,4 mm, was applied during welding tests.

When the material was being prepared for welding, sections were chamfered in order to ensure the required weld penetration and to facilitate welding (Figure 1c). Sections were butt welded with the application of process parameters selected for the arc ignition phase, welding of a curve and straight line, and crater filling. Maximum and minimum intensity of welding current, wire feed rate, and welding rate and frequency were selected for every phase of welding.

Tensile strength tests were conducted according to standard PN-EN ISO 15614-2 by means of an Instron 4483 strength tester with measuring head, with a max load of 20 kN. Vickers HV 0,1 hardness measurements were performed according to the requirements of standard PN-EN ISO 6507-1:2007. Metallographic specimens were etched electrolytically in a 1,77 % HBF4 solution and examined under an Eclipse L150 light microscope (Nikon) with NIS Elements image analysis software.


a)

b)

c)

Figure 1 Test station for TIG welding processes: a) general view, b) welding robot, c) method of material fastening

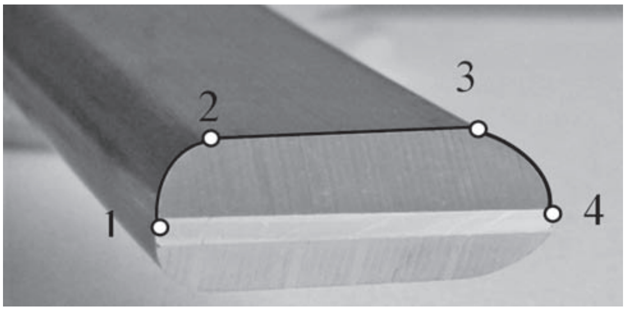


Figure 2 Diagram of section welding in steps*:* 1 Arc ignition, holding, 1 - 2 Welding of a curve, 2 - 3 Welding of a straight segment, 3 - 4 Welding of a curve, 4 Crater filling

RESULTS AND DISCUSSIONS

The first verification of welded joints was carried out by means of macroscopic tests in order to determine optimal welding parameters. A welding process consisting of several steps was developed for further tests, the steps being: arc ignition, welding of a curve (with a specific radius), welding of a straight segment, welding of the second curve, and crater filling (Figure 2). The same procedure was applied to the other side of sections, after samples were rotated by 180 °. In Table 2 selected welding parameters are presented.

Only welded joints with very good appearance and quality, made using the parameters indicated in Table 2,

Table 2 **Welding parameters of sections made of AlMg3, AlMg4,5, AlMg5, AlMg7 alloys**

AlMg3	I_{min} / A	I_{max} / A	V_{wire} / m/s	Hz / Hz	V_{weld} / m/s
1	100/ 70	100/70	0,0083/0,0117	3/ 1	0,0083/0,0028
1 - 2	120	215	0,02	1,2	0,0028
2 - 3	155	225	0,63	2	0,004
3 - 4	35/ 20	65/ 40	0,0416/0,0083	1/ 1,2	0,33/ 0,258
4	20	20	0	0	0
AlMg4,5	I_{min}	I_{max}	V_{wire}	Hz	V_{weld}
1	100/ 120	100/215	0,0083/0,02	3/ 1,2	0,0083/0,028
1 - 2	155	225	0,063	2	0,004
2 - 3	20	40	0,0083	1,2	0,033
3 - 4	20	40	0,0083	1,2	0,0258
4	20	20	0	0	0
AlMg5	I_{min}	I_{max}	V_{wire}	Hz	V_{weld}
1	100/ 100	100/125	0,0083	1/ 1,2	0,083/ 0,17
1 - 2	115	200	0,02	2	0,004
2 - 3	155	225	0,033	2	0,033
3-4	20	40	0,0083	1,2	0,033
4	20	20	0	0	0
AlMg7	I_{min}	I_{max}	V_{wire}	Hz	V_{weld}
1	100/ 70	100/70	0,083/ 0,0116	3/ 1	0,083/ 0,0028
1 - 2	115	215	0,02	1,2	0,0028
2 - 3	155	225	0,063	2	0,004
3 - 4	20	40	0,083	1,2	0,033
4	20	20	0	0	0

were subjected to tensile strength tests. Tensile strength test results of a solid section and a section after the welding process are compiled in Table 3.

The strength of solid, extruded sections is dependent on the amount of Mg dissolved in the solid solution. Welded joints broke at the weld for alloys with magnesium content above 4,5 %. The greater the Mg content, the greater the difference between the strength of the solid section and the welded section. As shown by the authors of paper [1], this may be the result of differing Mg content in the weld and native material, because the process of magnesium evaporation may occur during the welding process.

Table 3 **Tensile strength of solid sections and welded joints**

		R_m / MPa	$R_{p0,2}$ / MPa
AlMg3	Native material	228	82
	Weld	223	85
AlMg4,5	Native material	291	116
	Weld	203	109
AlMg5	Native material	299	137
	Weld	163	124
AlMg7	Native material	372	179
	Weld	205	166

This is why these differences are so visible at high Mg contents and in sections where the weld is larger, and thus, the welding process is longer. Such a phenomenon was not observed in the case of welding strips with a thickness of 2 mm, where material was welded in a single step [3]. As shown in Figure 3, there is a lower percentage of strength reduction for yield point than for the R_m parameter – tensile strength.

The influence of Mg content can also be seen in the hardness value. HV 0,1 hardness distribution for individual joints of the alloys subject to analysis is presented in Figure 4 along with an example of indentation positions on the joint of a section made of AlMg4,5 alloy.

Hardness tests on the cross-section of welded samples made of alloys with Mg content up to 5 % did not show significant growth or reduction of hardness in relation to welding, which was confirmed by offset yield stress results. Such reduction could be observed for the alloy with Mg content above 7 %, which can be explained by mixing of the flux, with 4,5 % Mg content, with the native material and obtainment of greater weld hardness than in the case of other alloys, but with hardness lesser than that of the native material.

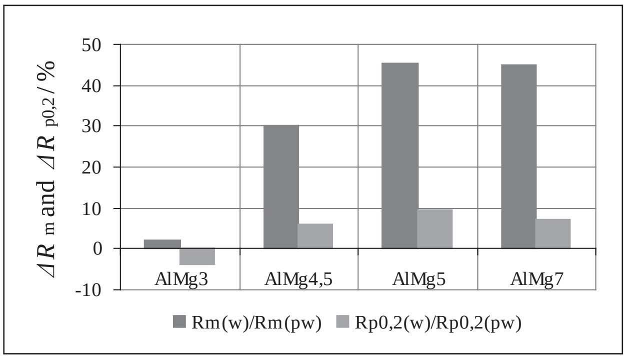
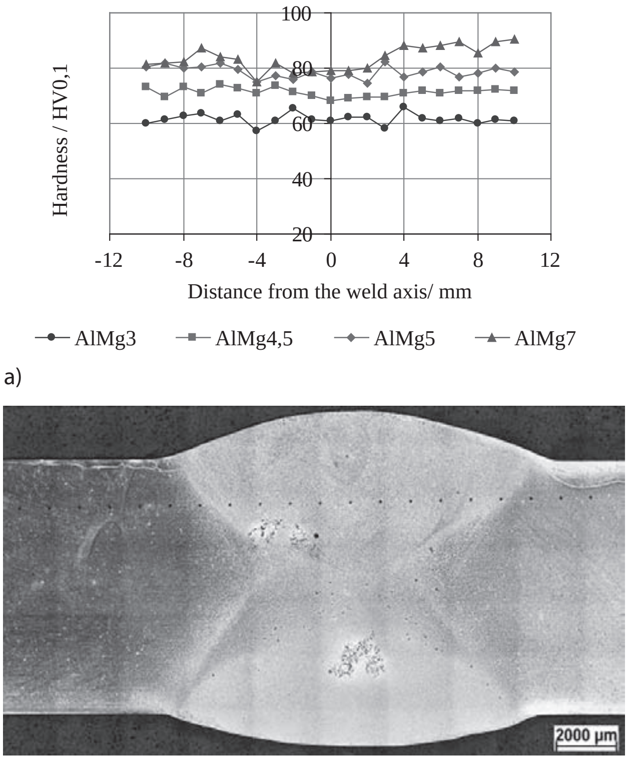


Figure 3 Percentage change in tensile strength (R_m) and offset yield stress ($R_{p0,2}$) of solid sections compared to welded sections



a)

b)

Figure 4 Hardness distribution in TIG-welded joint (a) and hardness distribution for AlMg4,5 alloy (b)

CONCLUSION

Parameters of TIG welding of a section with thickness of 8 mm were determined as a result of testing of the weldability of sections extruded from 5xxx series aluminum alloys with Mg content from 3 to 7 %. An automatic welding method in successive steps was developed for different current parameters (Figure 1, Table 3).

These alloys exhibit high weldability and no significant reduction of yield point in welded sections. Tensile strength (R_m) is reduced, and the change in strength increases as Mg content grows. Such differences were not observed in earlier studies of sections with thickness up to 2 mm [3]. These alloys are also characterized by unprecedented uniformity of hardness distribution in the welded joint, in comparison to 6xxx alloys, and no change in hardness in the heat-affected zone. Sections extruded from 5xxx series aluminum alloys (particularly with Mg content above 5 %) have rarely been used in structures until now due to their resistance to deformation (hard-deformability).

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Note: The responsible translator for english languages is Karol Dobryniewski, Razut, Poland