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Repair of magnesium alloy castings by means of welding and pad welding

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Materials

ABSTRACT

Purpose: Attempts were carried out at pad welding and welding of castings made of alloy AZ91D. Technologies were developed to repair such castings by means of welding methods encompassing the choice of weld deposit, welding parameters, heating parameters and the technique of welding.

Design/methodology/approach: The research were focus on encompassed: pad welding and welding tests on flat plates cut out from a pig sow of the AZ91D alloy, tests of pad welding of a cast element, making holes simulating defects by means of material removal and their welding.

Findings: The results of investigation were to elaborate the repairing technology of the defects in Mg alloy cast elements and selection of the welding method, weld deposit and welding parameters for castings to be made of magnesium alloys.

Research limitations/implications: The repair by the means of welding must be made after solution heat treatment. It is recommended that the solution heat treatment should be conducted for 24 hours at a temperature of 415ºC, so that the β-Mg17Al12. massive phase is sollubilized. It has been found that when making repairs with the use of welding technologies, alternating-current sources should be applied.

Practical implications: Presented results and conclusions have been applied to work out the technology for repairing of cast elements in aircraft industry.

Originality/value: Repairing of cast elements in aircraft industry is necessary to assure the economical results of manufacturing of huge cast Mg alloy elements as well as a good quality of it.

Keywords: Metallic alloys; Magnesium alloys; Welding

1. Introduction

There are a number of Mg alloys, both casting ones and those for plastic working, intended for operation at a room temperature, as well as alloys characterized by elevated strength properties and creep resistance which may operate at elevated temperatures (up to 370°C). In case of a majority of magnesium alloys, along with an increased amount of alloying additions, the range of solidification temperatures usually expands, which results in increased susceptibility to cracking during welding [1, 2].

Weldability of a majority of magnesium alloys is good [1, 2]. However, welding and pad welding of cast elements cause many problems, inter alia due to the susceptibility of Mg alloys to hot cracking, strong rigidness of the surfaces joined in a casting, the effect of chemical composition segregation and precipitation of intermetallic phases on grain boundaries [3]. Some examples of cracks in the repaired magnesium castings are presented in Fig. 1.

The purpose of the study was to develop a technology of repair of AZ91D alloy castings by means of welding and pad welding. The scope of the research encompassed:

- pad welding and welding tests on flat plates cut out from a pig sow of the AZ91D alloy,
- tests of pad welding of a cast element (AZ91D),
- making holes simulating defects by means of material removal and their welding (alloy AZ91D),

- development of a technology to remove the defects and repair the element cast,
- selection of the welding method, weld deposit and welding parameters for castings to be made of magnesium alloys.

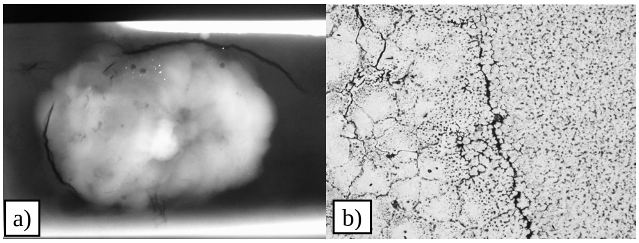

Fig. 1. Examples of hot cracks in the heat affected zone (HAZ) in the repaired AZ91D alloy castings: a) X-ray photography, b) weld microstructure

2. Research material

For the first stage of the research, test plates cut out from a pig sow of the AZ91D alloy of dimensions: 280x60x6 mm were used. The plates were X-rayed to determine their quality. Only plates without casting defects were selected for the tests. At the second stage of the research, fragments of a transmission pan made of the AZ91D alloy cast into a sand mould were used. The chemical composition of the filler metal is shown in Table 1.

3. Research methodology and results

3.1. Tests of pad welding and fusion welding of test plates cut out from a pig sow

The test plates cut out from pig sows were pad welded and fusion welded by TIG method (141- nonconsumable electrode in tungsten inert gas). A single-run and a multiple-run padding welds were made. Next, a through-hole was milled to simulate material removal to form a defect of dimensions: 50x10 mm, which was then welded. Both pad welding and fusion welding were carried out using a current source FALTIG 400 AC/DC and applying alternating current. The facility is equipped with a system to facilitate the control of current intensity during arc ignition as well as during its putting out. The current rise time was set at 2 s to the predefined value and the arc extinguishing time at 4 s. A tungsten electrode, 2.4 mm in diameter, was used. Technical argon 99.995 of flow intensity of 10 l/min was applied as shielding gas. Free gas outflow when beginning the welding was set at 3s, and at 4s for finishing the welding process. The pad welding and fusion welding parameters are shown in Table 2, entries 1-6. Fusion welding was performed with string beads. Fig. 2 shows the test plates after pad welding and fusion welding.

The padding welds made by means of the Castowig 45859W wire were characterized by a correct weld face position and few pores in the weld face. In the case of all double-sided welds, cracking in the heat affected zone was observed (Fig. 3).

Metallographic examinations were carried out on a stereoscopic microscope, OLYMPUS SZX9, and a light microscope, OLYMPYS GX71, equipped with a DP-70 camera and the AnalySIS image acquisition system. Metallographic specimens were prepared in compliance with the procedure elaborated at the Department of Materials Science, Silesian University of Technology [2].

For etching, a reagent of the following chemical composition was used: 10 ml HF + 96 ml H_2O. The results of the investigations are presented in Fig. 3 for welding with the use of rods from Gorzyce and in Fig. 4 for a weld made with CASTOWIG wires.

Based on the research results obtained, it has been found that:

- the face of the padding welds, the fusion penetration and the macrostructure are correct both in the single-layer and multi-layer padding welds;
- few bubbles are present in the last layer of padding weld, which is acceptable;
- incomplete fusions and hot cracks appear in the heat affected zone in the double-sided weld.

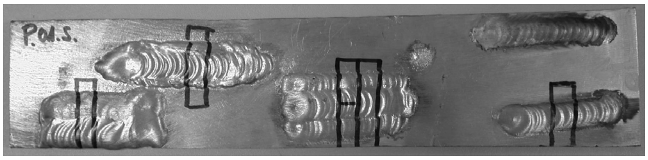

Fig. 2. Overview image – sample welding plate – feller material: CASTOWIG 45859W

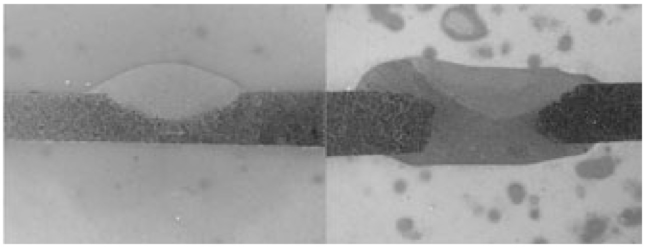

Fig. 3. Macrostructures of welds and padding welds executed (Table 2, pos. 1)

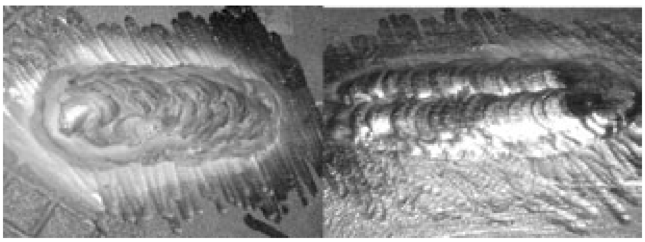

Fig. 4. Overview of the repair weld on a casting (AZ91D): a) back of the weld, b) root of the weld

Table 1.
Chemical composition of filler material used for welding sow

Entry	Name	Dimension [mm]	Al	Mn	Zn	Zr	Si	Mg	note
1	Wire: Castolin CASTOWIG 45859W	3	5,64	0,33	0,62	<0,005	0,01	rest	Fe<0,007

Table 2.
The parameters used for pad welding and welding of test plates from pig sow

Entry	fusion weld	Preheating [°C]	Gas [l/min]	I [A]	Current	Note
1		-	Ar 10	100	~ AC	
2		-	Ar 10	90	~ AC	
3		-	Ar 10	80	~ AC	
4		200°C/2h	Ar 10	70	~ AC	PWHT 250°C/2h
5		-	Ar 10	80	~ AC	Solution heat treatment 415°C/24h

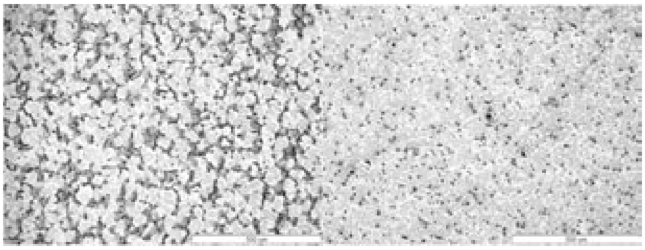

Fig. 5. Microstructure of the repair area (mag. 100x): a) base material, b) weld

3.2. Tests of welding AZ91D alloy castings

Tests of welding were carried out on fragments of a transmission pan casting made of the AZ91D alloy. To simulate the region after casting defects removal, holes of 50 x 10 mm were milled in the specimens. The welding region was cleaned mechanically by surface milling at a distance of ca. 2 cm from the edge of the defect. The holes were then welded at a stand presented in chapter 3.1, with parameters shown in Table 2, entry 7. In addition, in order to avoid welding inconsistencies in the form of cracking in HAZ, specimens of the castings were heated for 2 hours at a temperature of 200 °C. After welding, stress relief annealing was performed at a temperature of 250 °C/2h. A ceramic backing and argon shielding were used to protect the process against oxidation from the root of weld side. The results of the test are presented in Fig.4. Fig. 5 illustrates the microstructure of the weld.

The attempt to repair the casting made of the AZ91D alloy in a condition after casting indicates the necessity to apply preliminary heating before welding for thicknesses above 20 mm in order to avoid hot cracking. In multilayer welds, hot cracks in HAZ were observed along with some instances of incomplete fusion and gas pores. However, the face of weld, its root and shape were correct (Fig. 4). Metallographic investigations of the region under repair revealed the presence of typical welded joint regions. The base metal was a dendritic system of a solid solution of aluminium in magnesium (α-Mg) with precipitations of β-$Mg_{17}Al_{12}$ massive phase along primary grain boundaries and large regions of the same phase, however, of lamellar morphology (Fig. 5a). In HAZ, the disappearance of the $Mg_{17}Al_{12}$ lamellar phase regions was observed (Fig. 5b), whereas the weld was characterized by uniform grain of the solid solution (α) with few $Mg_{17}Al_{12}$ phase precipitations (Fig. 5b). The cracks appeared along the line of fusion, which is caused by the presence of the β-$Mg_{17}Al_{12}$ phase along the grain boundaries in HAZ and by high welding stresses resulting from rigidness of the casting.

In order to avoid the presence of the β-$Mg_{17}Al_{12}$ massive phase, the casting was subjected to solution heat treatment using a weld annealing facility. The heat solution treatment was performed with the use of resistance mats insulated with heat-insulating wool. The casting was heated up to the temperature of 415°C and soaked for 24h. The element so prepared was welded with a double-sided weld, string beads, in accordance with the parameters presented in Table 2, entry 5. Assessed visually, neither the face nor the root of the weld showed any defects or inconsistencies (Fig. 6a). The non-destructive tests carried out, i.e. both liquid-penetrant and roentgenographic examinations, have not shown any welding inconsistencies. The few gas pores that were revealed meet the requirements of the recipient societies. Macrographic examinations of the casting fragment have confirmed that the welding technique and technology applied were correct. No cracks, fusions or gas pores were detected. The weld fusion was correct. At the same time, no contamination or oxidized surfaces could be observed at the spot where the weld was subjected to prewelding (Fig. 6b). Additionally, attempts were made to repair, after solution heat treatment, an element which had already been welded.

It was found that the second and the subsequent repairs of the same region were possible only after another solution heat treatment of the casting. The making of the second repair without solution heat treatment results in hot cracking as well as in cracking caused by over-rigidness of the system in both HAZ and in the weld.

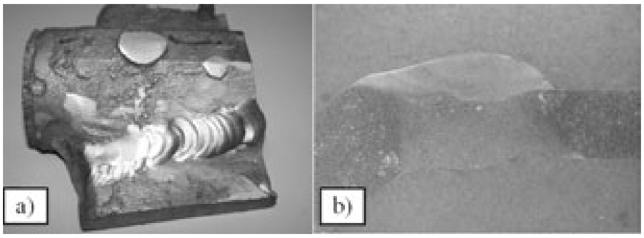

Fig. 6. Welded element cast from the AZ91D alloy: a) view of the repaired fragment cut out for the metallographic examination, b) macrostructure of the region of repair

4. Conclusions

The problem of fusion welding and pad welding of elements made of magnesium alloys is very significant in the aviation industry. The pad welding and fusion welding tests together with the examination of joints have allowed the elaboration of guidelines to be followed when repairing casts made of AZ91D alloys. Information on hot and polygonization cracks in the temperature range apt for crystallization and temperatures characteristic of HAZ has been obtained. It has been found that structural and design factors related to the geometry of joints (over-rigidness) have a large impact on cracking.

A technology of AZ91D alloy castings repair has been developed. It has been found that when making repairs with the use of welding technologies, alternating-current sources should be applied. They should be equipped with a foot-operated current intensity control unit, which facilitates the control during the welding process. Low intensity current of ca. 70-80 A should be used and the welding process should be performed with string beads, by the means of a wire of a similar chemical composition e.g. CASTOWIG 45859W. The interbead temperature should remain at about 200^{o}C. Preliminary heating at 200^{o}C should be applied for the elements whose thickness exceeds 20 mm or for castings with walls of diverse thickness. The repair by the means of welding must be made after solution heat treatment. It is recommended that the solution heat treatment should be conducted for 24 hours at a temperature of 415^{o}C, so that the β-$Mg_{17}Al_{12.}$ massive phase is sollubilized. Fusion welding or pad welding may be only made once. It is not allowed to re-repair the region that has already been welded. After the repair has been completed, the alloy should be subjected to relief annealing at a temperature of 250^{o}C.

Acknowledgements

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