Diffusion welding in vacuum of homogeneous joints of alloy AlMg3

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Abstract: Diffusion welding was used to join aluminium alloy AlMg3 in order to measure electrical properties of jointed samples and analyse diffusion process. There were created magnesium oxides which had the influence on the quality of joins. The main parameters of welding (temperature, time and pressure) and preparation of samples influenced the creation of the oxide layer in joints. Alloy AlMg3 was selected because of easy correlation with welding parameters, diffusion process and electrical properties.

Keywords: diffusion welding, AlMg3, magnesium oxide, electrical resistance

1. Introduction

The diffusion welding is a special welding technology joining parts in solid state, when the welded parts are in close contact under controlled pressure to defined temperature and time, which are main parameters of the diffusion welding. Next parameter is geometry of contact surfaces (preparation of contact surfaces) because the contact surfaces must be plan for tight contact between welded parts. Approximation of contact surfaces and local plastic deformation between contact surfaces enabling atomic diffusion of welded parts and creation of high strength joint are necessary conditions.

Use of the diffusion welding is mainly for joining materials with problematic weldability or for welding different materials in cases when a fusion welding would create brittle phases.

The process of the diffusion welding consists of 3 theoretical steps:

1) First contact of surfaces – elastic and plastic deformation of small areas

2) Diffusion of atoms – movement of dislocations and vacancies, original interface ceases to exist, creation of new grains

3) Intensive diffusion – new interface of welded parts is created

The aim of this research was to weld samples and to measure the electrical properties of the welded samples, which could become the qualitative parameter for evaluation of the welded samples in future. This research was carried out in cooperation among Forschungszentrum Jülich, RWTH Aachen and CTU in Prague. Currently, another research is being realised.

2. Material and preparation of samples

As basic material was used aluminium alloy AlMg3 (EN AW-5754) for homogeneous joint; its composition is shown in table 1. This alloy was selected for good welding properties to avoid the formation of complex intermetallic phases in order to carry out the comparison of electrical properties in depending on the welding parameters. The solidification range of AlMg3 is between 610 - 640°C. Main usage of this alloy is for the production of tooling, machines and machine parts and pressure containers.

Table 2 shows the chemical composition of samples which was used for experiment. The spectrometer measuring shows an increased volume of magnesium in the used alloy.

For the experiment circulars samples of diameter 50 mm and height 50 mm were prepared; their dimensions are shown in the figure 1.

The condition of the surface is in the figure 2 which shows that surface after machining had R_z=2.84 µm, R_{max}= 6.88 µm and R_a=0.35 µm. Planarity of surface from 10 points was 2.84 µm which is more important for quality of the diffusion join than roughness. Before the welding process the contact surfaces were for 1 minute etched in solution: 80 ml H_20 + 5 ml 40 % HF. After etching, the samples were placed immediately into the furnace.

Table 1 Chemical composition EN AW 5754 – AlMg3

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Mn + Cr
0.40	0.40	0.10	0.50	2.6-3.6	0.30	0.20	0.15	0.1-0.6

Table 2 Chemical analysis of used material AlMg3

Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Sn	Ti
0.227	0.400	0.0644	0.300	3.02	0.0891	0.00650	0.0787	0.0127	0.00210	0.0243
Be	Bi	Ca	Na	P	Sb	Sr	Li	V	Zr	Al
0.00050	0.00140	0.00280	0.00190	0.00170	<0.001	0.00020	<0.00080	0.0107	0.00140	95.8

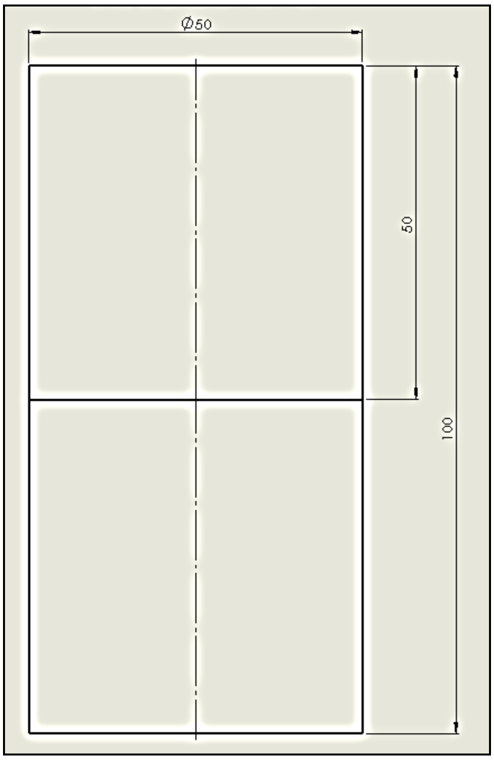

Figure 1 the dimensions of samples

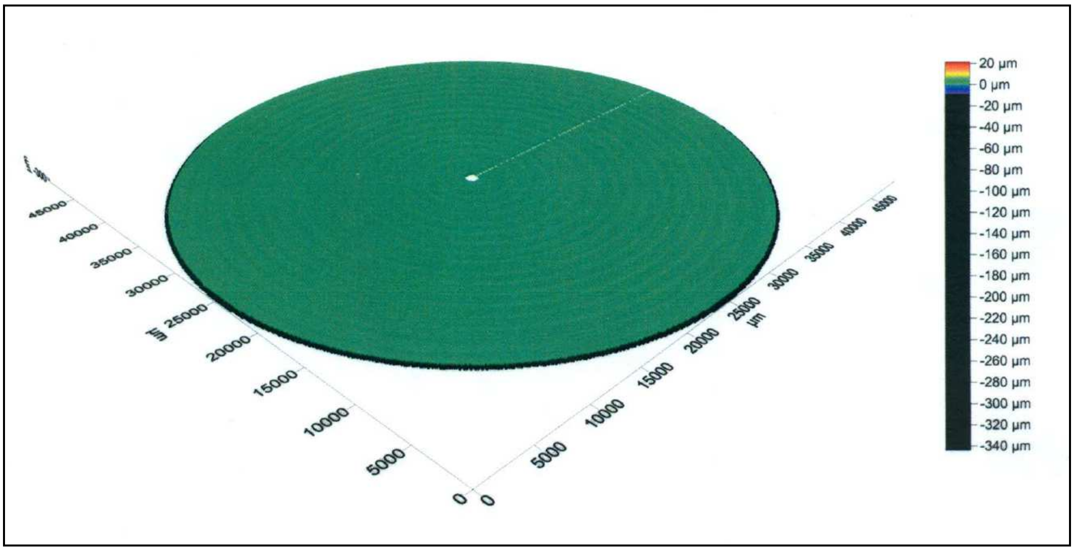

Figure 2 the surface finish of samples' contact surfaces

3. Diffusion welding of samples

The samples were welded in vacuum furnace from the company PVA TePla. This is high vacuum system with cold wall and integrated pressing unit and power-regulated resistance heater elements for application of the diffusion welding.

Maximal pressing force is 1 500 kN (controllable up to 1 000°C), working pressure range 1 x 10^{-6} mbar, work space: 300 mm width, 300 mm depth, 250 mm height. The diffusion welding machine is shown by the figure 4.

Overall, there were 5 samples of AlMg3 welded. The table 3 shows the main parameters for all 5 samples which resulted from the previous research. The welding temperature and the pressing force (T=500°C, F=9 kN) were the same for each sample and varied the welding time. The pressing force on surface of diameter 50 mm was 4.8 MPa. The welding temperature was 78-82% from melting temperature of AlMg3.

The welding process is described in the figure 3 which shows graph divided into 3 parts: A, B and C. Part A is heating with heating rate 1.4 °C/min. Part B is the main part of the diffusion welding with the bonding time: 300 , 400 and 500 minutes to temperature 500°C under pressure 4.8 MPa. Part C is cooling part which was free in vacuum. The figure 5 shows all five welded samples.

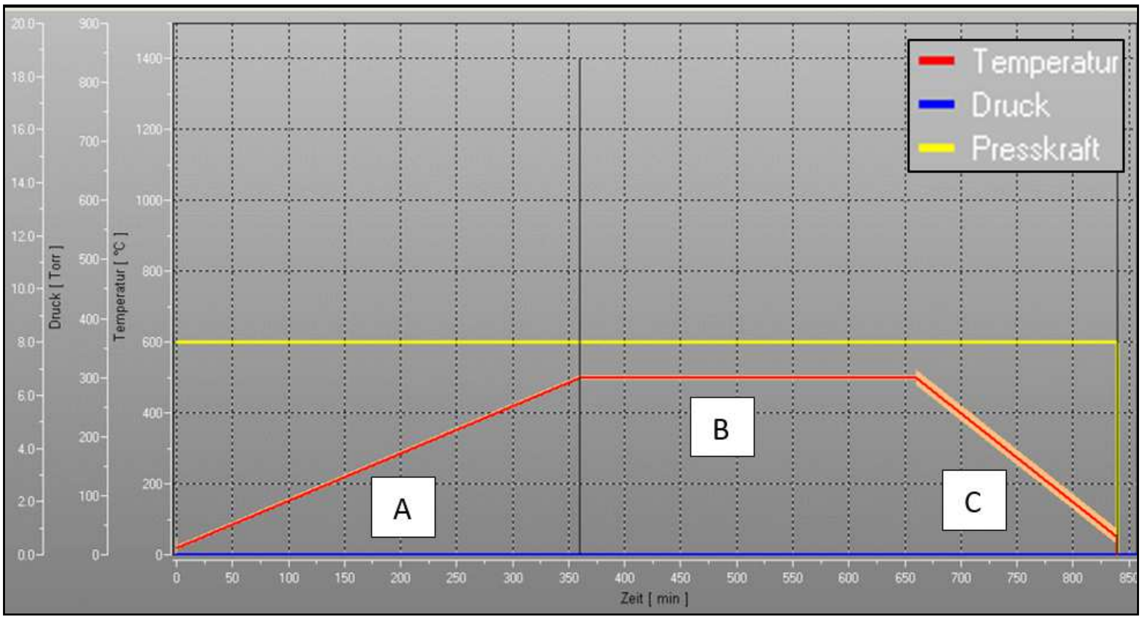

Figure 3 Process of the diffusion welding of the welded samples – Y axles from links: Force [kN], Pressure, Temperature

Figure 4 Diffusion welding machine in FZ Jülich

Table 3 Main parameters of diffusion welding and deformation of welded samples

Sample	Temperature [°C]	Time [min.]	Force [kN]	Deformation [%]
I	500	500	9	11.1
II	500	400	9	12.4
III	500	300	9	17.6
IV	500	500	9	14.9
V	500	300	9	13.6

Figure 5 Welded samples

4. Results

Microstructure

The welded samples were cut and observed by optical microscopy. The results of all these are shown by figures 6 - 10. As can be seen from the figures, the welding time has not influenced the joint interface very much. Theoretically, the joint interface should not be visible at all after the diffusion welding. In our case, there are indicated dark layers, with average thicknesses 1-1.8 µm and dark particles as shown for example in the figure 7.

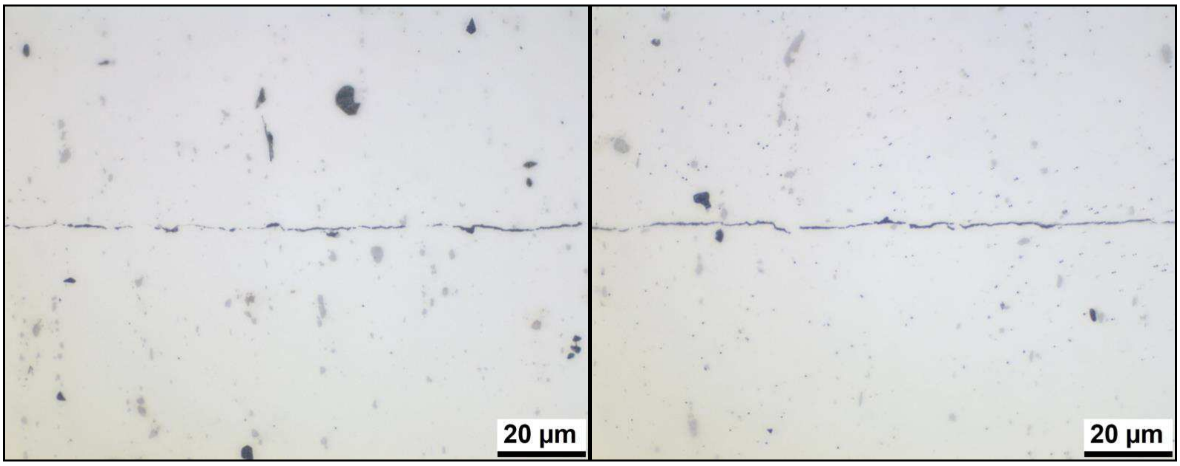

Figure 6 Sample 1 - created at 500°C, 500 min., 4.8 MPa and Sample 2 - created at 500°C, 400 min., 4.8 MPa

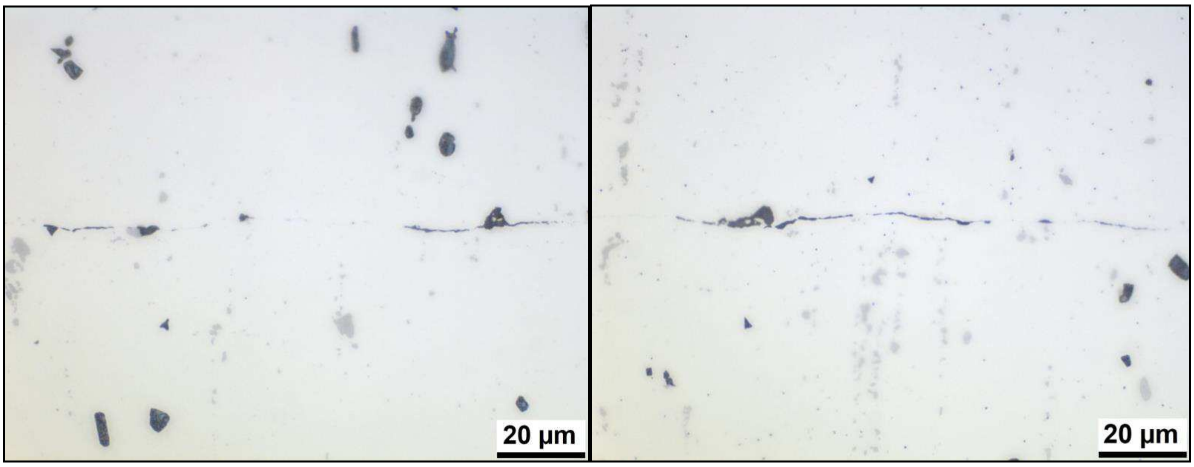

Figure 7 Sample 3 - created at 500°C, 300 min., 4.8 MPa and Sample 4 - created at 500°C, 500 min., 4.8 MPa

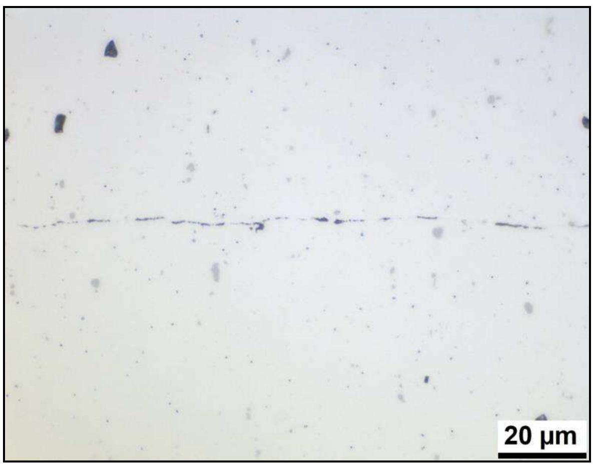

Figure 8 Sample 5 - created at 500°C, 300 min., 4.8 MPa

SEM result – chemical composition

The chemical composition of the dark particles and layers at the joint interface was analysed by SEM-scanning electron microscope.

The figure 9 and table 4 show the result of the SEM analysis. The spectrums P1, P2 and P5 have increased volume of magnesium and oxygen. The values of silicon are residues after metallography preparation.

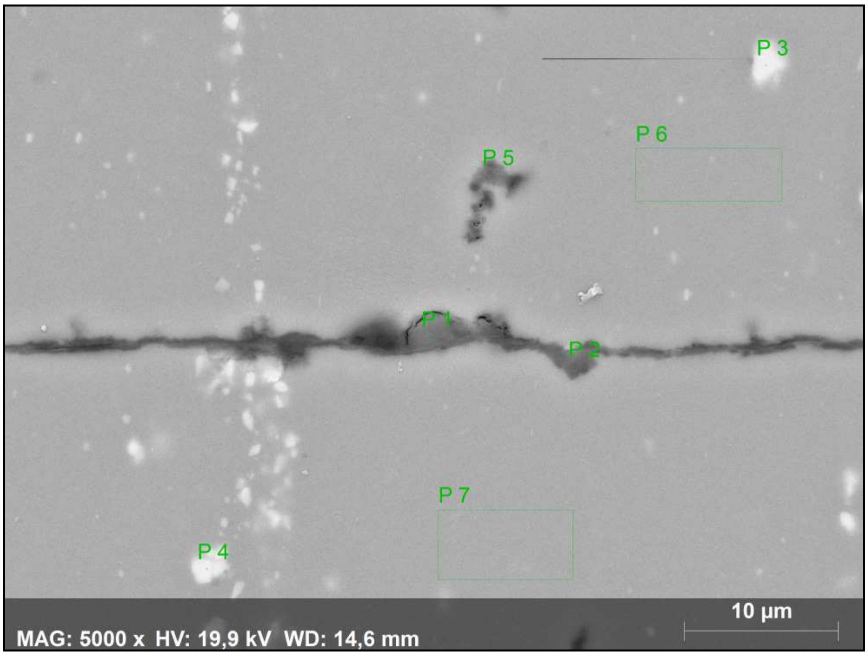

Figure 9 SEM analysis

Table 4 SEM analysis of the dark particles and layers [at. %]

Spectrum	O	Mg	Al	Si	Mn	Fe
P1	8.33	2.61	78.51	10.29	0.13	0.13
P2	6.50	5.05	72.78	15.50	0.13	0.04
P3	0.00	1.72	70.10	2.64	10.49	15.04
P4	0.00	2.83	76.70	2.15	4.10	14.22
P5	3.27	2.97	89.70	3.92	0.14	0.00
P6	0.28	3.04	96.34	0.08	0.25	0.02
P7	0.40	3.05	96.30	0.09	0.20	0.06

Measurement of electrical properties of the welded samples

The welded samples were measured on the instrument for measurement of electrical resistance. DC electrical resistance were compared with a reference sample without a weld which was also made of aluminium alloy AlMg3 with the same dimensions as the samples for the welding. The value of measurement of electrical resistance are in the table 5.

Table 5 Measurement of electrical resistance

Sample:	[μm mm^2/mm]
Sample I	204,58
Sample II	282,35
Sample III	208,95
Sample IV	252,13
Sample V	206,98
Reference	259,40

5. Discussion

Theoretically, after diffusion welding of homogenous joints, the joint interface should not by visible. But in our research, the joint interface is visible as it is shown in the figures 6 - 8. According to the recrystallization theory, the new grains should create a common phase between the welded parts and these new grains should belong to both welded parts. In our case it is not like that and in the position of the joint interface dark layers and particles formed of oxides were indicated. These oxides consist of elements: magnesium, aluminium and oxygen. The chemical analysis of used samples discovered the increased volume of magnesium in the used alloy, which led to a rapid formation of magnesium oxide which prevented to form the development of a common joint interface of welded samples.

The measurement of electrical resistance shows that the sample 2 and sample 4 almost too are close to the reference sample. Theoretically, these samples should be very well welded but the figure 6 and 7 show the oxides layers in all figures. For the precision and accuracy of the measurement it is necessary to measure a larger amount of samples.

6. Conclusion

The magnesium oxides were formed in the interface of joint during the welding process. The increased volume of magnesium in the used alloy influenced a rapid creation of these oxides between the preparation of the welded samples and welding process of these. In this research the electrical resistance of welded samples was measured. The research is now underway.

For this research the following steps are planned: next diffusion welding of the alloy AlMg3, which will be compared with these results of microstructure and measurement of electrical resistance. The measurement of electrical resistance should be dependent on frequency, on AC.

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