Ultrasonic Testing of Diffusion Bonded Joints of AlMg3

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The Diffusion welding was used to join aluminium alloy AlMg3 in order to make ultrasonic testing of diffusion bonded joints and analyse diffusion process. This ultrasonic testing should be used to compare with other non-destructive testing methods which the Institute of Manufacturing Technology of CTU in Prague develop. The paper discusses the ultrasonic testing for the diffusion bonded joints of AlMg3 and magnesium oxide which was created and which had an influence on quality of the diffusion bonded joints. The Alloy AlMg3 was selected because of easy correlation with welding parameters, ultrasonic testing, metallographic examination and preparation of samples for the diffusion welding.

Keywords: diffusion welding, AlMg3, magnesium oxide, ultrasonic testing

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 plane 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. The diffusion welding is mainly used for joining materials with problematic weldability or for welding different materials in cases of creating brittle phases.

The Diffusion welding is being used in aircraft, optic and electrical industry, where special alloys or combinations of metal or non-metal materials are often used. The alloys and materials come from limited sources and therefore they are expensive as well. These reasons lead to the fact that the destructive testing of diffusion bonded joints is not sufficient for the industry and the used components in operation.

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 of the alloy AlMg3 and to make the ultrasonic testing of the welded samples which could become the qualitative testing method for evaluation of the welded samples in future. In our research we are developing another non-destructive method of the measurement of the electrical properties and this research of ultrasonic testing of the diffusion bonded joints could be a next possible method used for non-destructive testing. The ultrasonic testing could be used to compare the measurement of the electrical properties of the diffusion bonded joints. This research was carried out in cooperation among Research Centre Jülich, RWTH Aachen and CTU in Prague. Currently, another research is being realised.

2 Material and preparation of samples

Aluminium alloy AlMg3 (EN AW-5754) was used as a basic material for homogeneous joint; its real chemical 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 dependence on the welding parameters. The solidification range of AlMg3 is between 610 - 640°C. The main usage of this alloy is because of the production of tooling, machines and machine parts and pressure containers.

For the experiment there were prepared circulars samples of diameter 50 mm and height 50 mm; their dimensions are shown in the figure 1. In the centre of one part of the sample was a drilling of diameter 10 mm and depth 5 mm which served as defined defect.

The condition of the surface is in the right part of figure 1 which shows that surface after machining had Rz=2.84 μm, Rmax= 6.88 μm and Ra=0.35 μm. Planarity of surface from 10 points was 2.84 μm which is more important for quality of the diffusion joint than roughness. Before the welding process the contact surfaces were for 1 minute etched in solution: 80 ml H20 + 5 ml 40 % HF. After etching, the samples were entered immediately into the furnace.

***Tab. 1** Real chemical composition of a used alloy AlMg3 [%]*

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.227	0.400	0.0644	0.300	3.02	0.0787	0.0891	0.0243	95.8

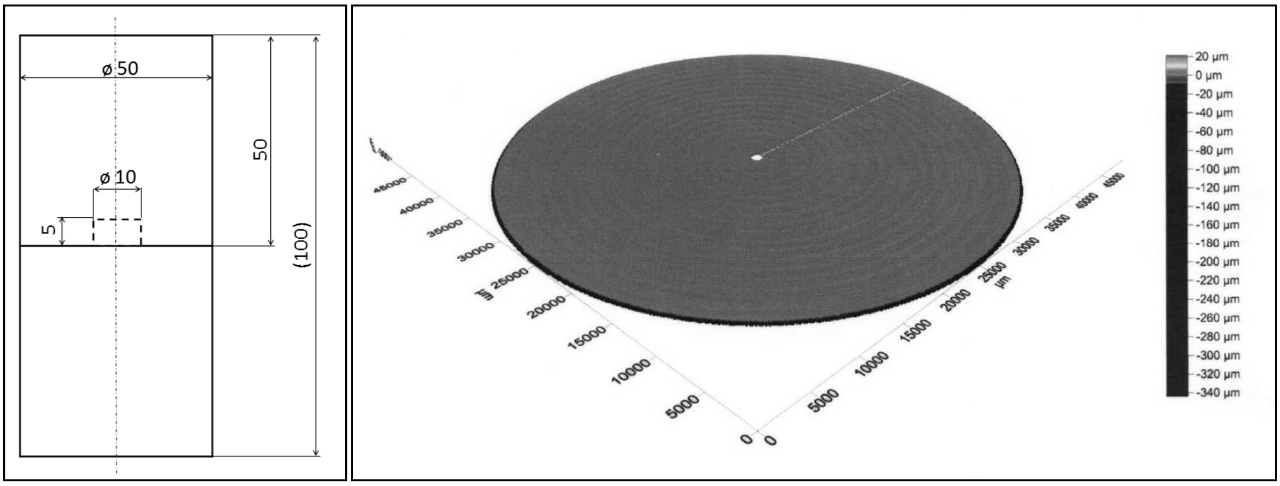

Fig. 1 *The main dimensions of samples and the contact, welding surface finish of used samples*

3 Diffusion welding process of samples

Five samples of AlMg3 which are shown on figure 2 were welded. The table 2 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 in 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 samples were welded in vacuum furnace from the company PVA TePla. This is a high vacuum system with cold wall and integrated pressing unit and power-regulated resistance heater elements for application of the diffusion welding.

The welding process is described in the figure 3 which shows a 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 a cooling part which was free in vacuum.

Tab. 2 *The main parameters of the diffusion process*

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

Fig. 2 *Diffusion bonded samples*

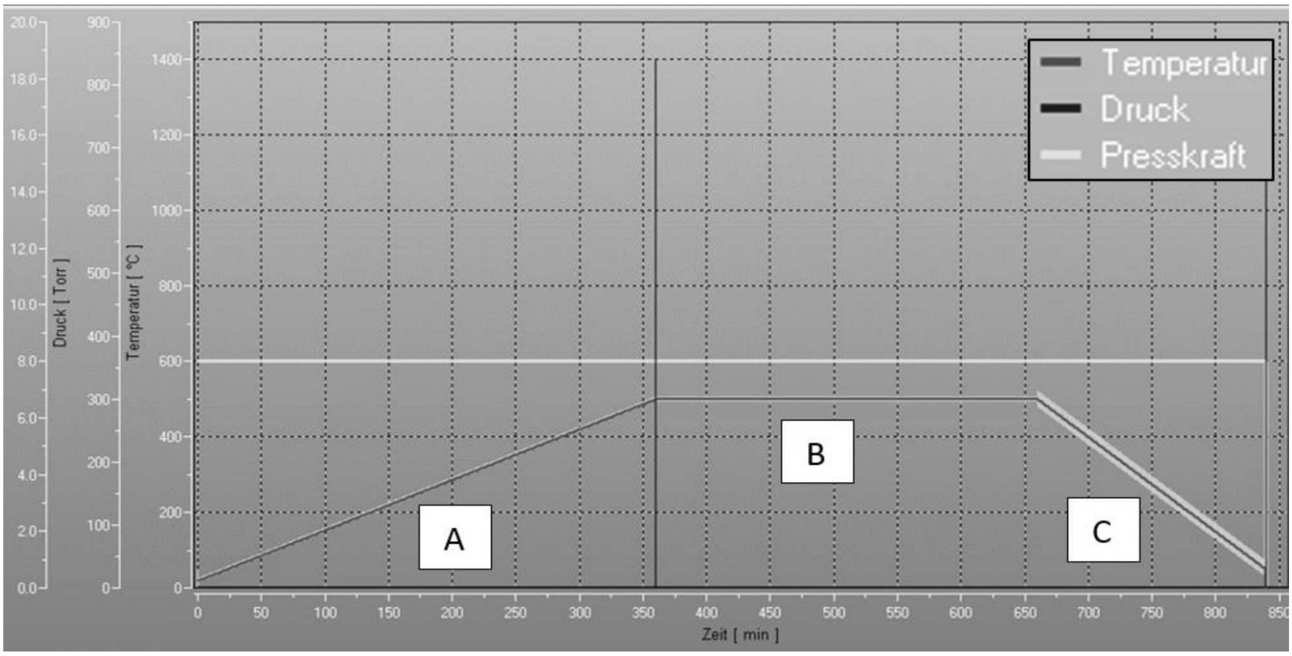

Fig. 3 *A set of diffusion welding process - Y axle from left: Force [kN], Pressure, Temperature; X-axle is time*

4 Results

Microstructure

The welded samples were cut into metallographic probes and then divided into quarters to observe a bonded line in the middle of probes by optical microscopy. The metallographic probes had the diameter 50 mm as welded samples and height was depended by concrete probe. The results of all these are shown by right part of figures 4 – 8. As can be seen from the figures 4 - 8, the welding time has not influenced on a 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.

Ultrasonic testing

An ultrasonic instrument Sonatest Prisma was used with a transducer RDT 2550 which has frequency 5 MHz and diameter 6,3 mm. A calibration was carried out with a gauge for aluminium alloy ATG – A1 (No. 0.002). For the ultrasonic testing second quarters by metallographic probes were used. The reference amplitude was set to 80 %. If the back echo by back wall of the probe is 80 % the joint should be relatively well welded.

Sample I

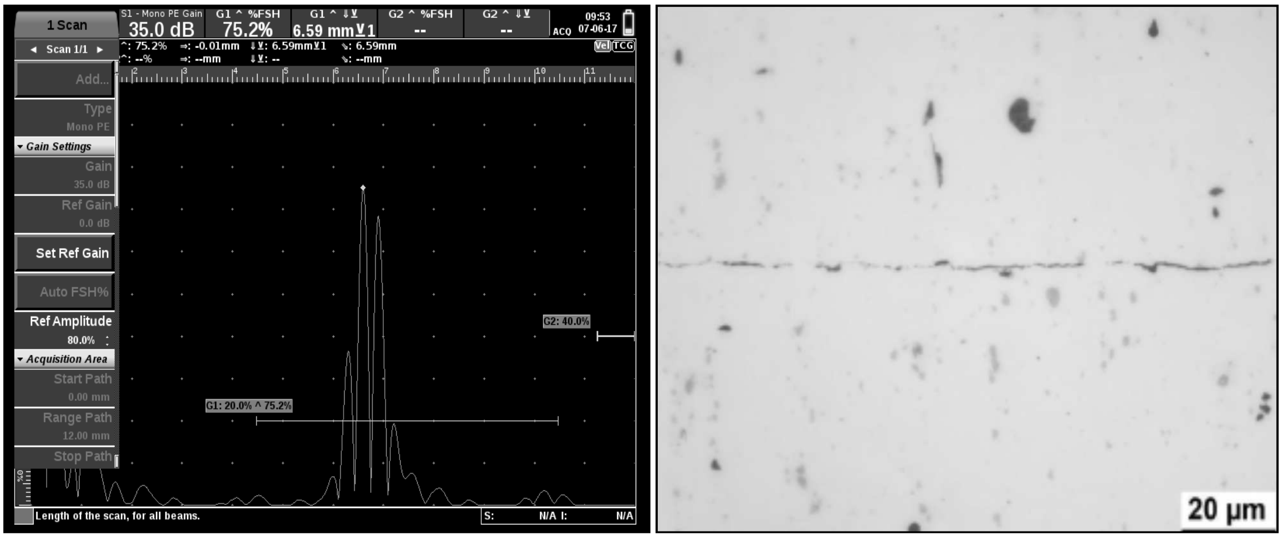

Fig. 4 *The results of sample I*

On the echogram (figure 4 – G1) there is visible an echo with 75.2 % of the reference amplitude in depth 6.59 mm by the bond line which is in the centre of the sample I. The bond line is seen on the right part of the figure 4 which forms a boundary between parent materials.

Sample II

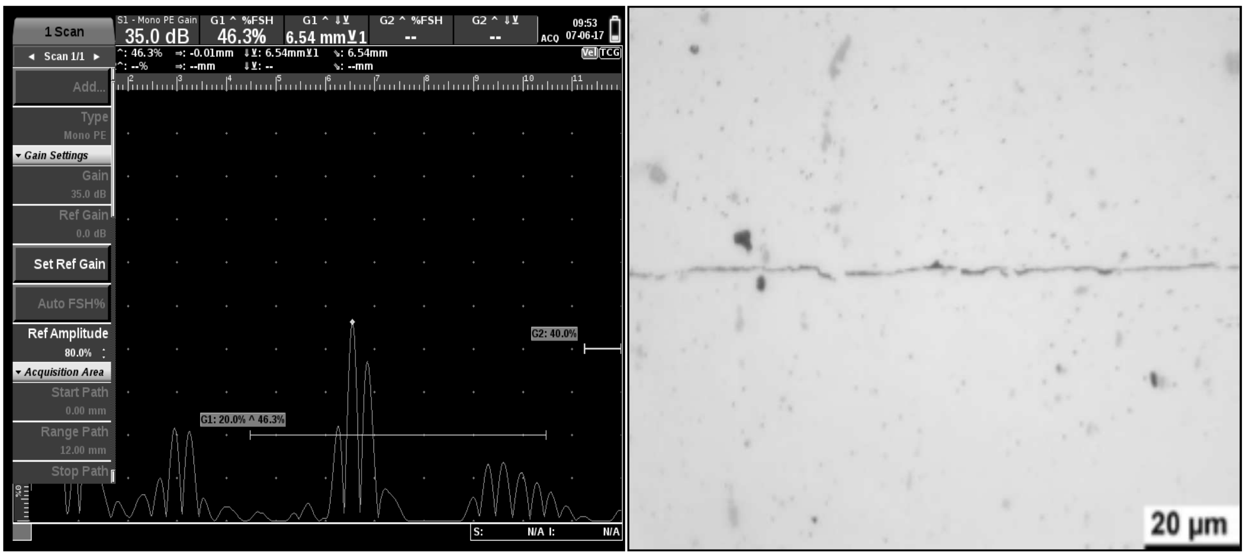

Fig. 5 *The results of sample II*

On the echogram (figure 5-left) there is visible an echo in depth 6.54 mm by the centre of the sample II there is the bond line of parent material. The bond line is in the centre on the right part of figure 5.

Sample III

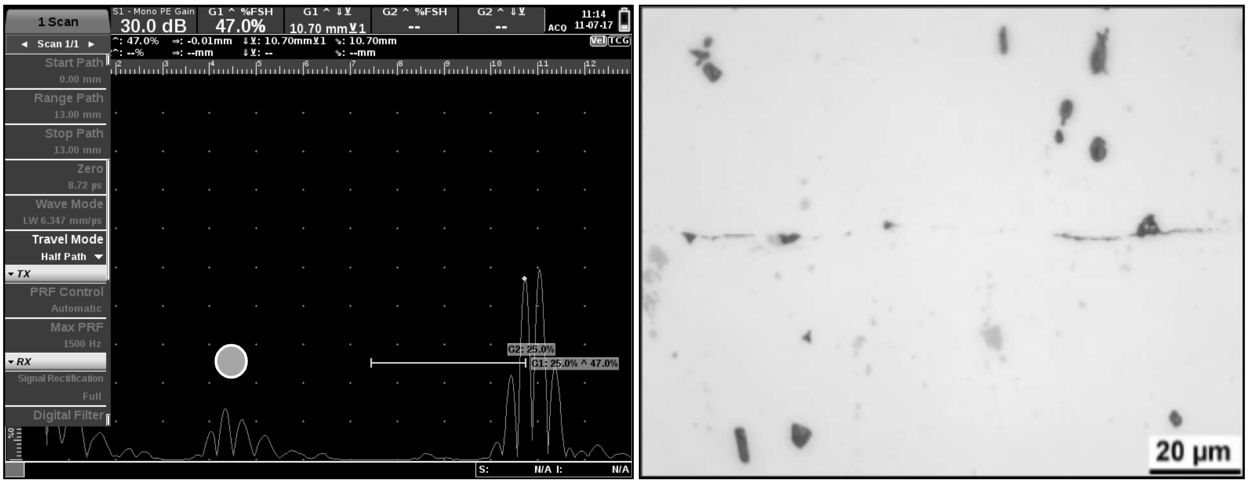

***Fig. 6** The results of sample III*

On the echogram (figure 6 - left) there is visible an echo by the back wall of the sample III. The parent material could be well welded but the metallographic examination shows (figure 6-right) the bond line in the centre. The bond line is visible but disconnected.

Sample IV

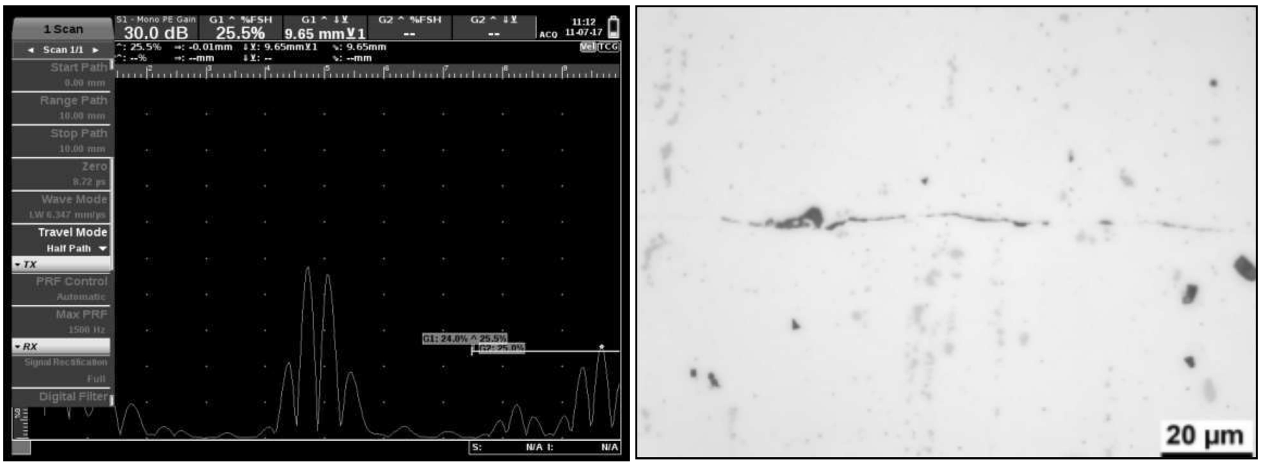

***Fig. 7** The results of sample IV*

On the echogram (figure 7 - left) there is visible an echo by the centre of the sample IV. This echo has about 35 % by the reference echo. The bond line of the sample IV is seen on the right part of the figure 4 which consists of a bigger dark particles.

Sample V

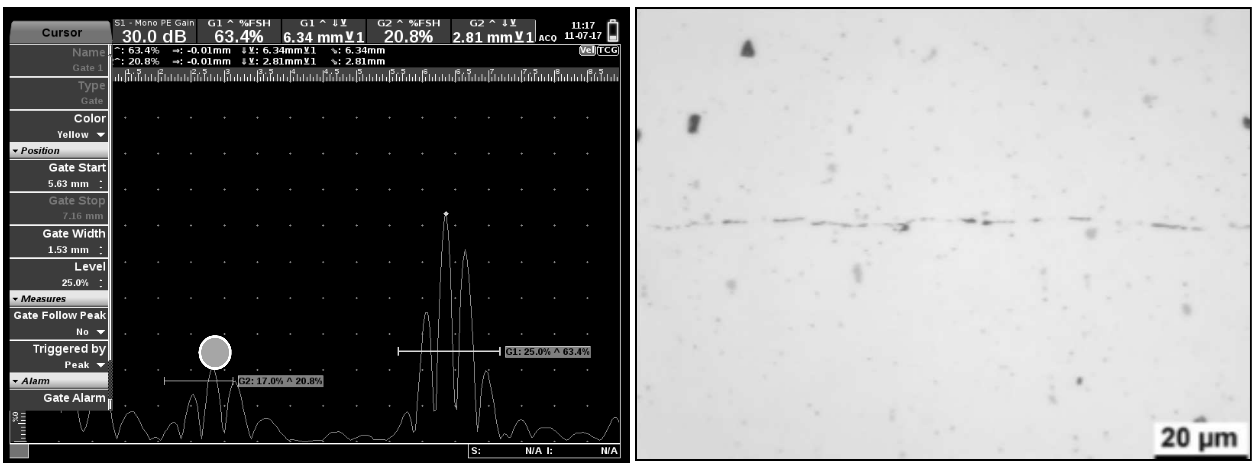

***Fig. 8** The results of sample V*

An echo by the back wall of sample V is visible on the echogram (figure 8 - left). The ultrasonic testing shows theoretically a good bonded joint but the metallographic examination of the sample V shows the visible disconnected bond line which is seen in the centre of the right part of the figure 8. The result of the sample V is almost the same as by the sample III in that the bond line is also disconnected.

SEM result – chemical composition

A chemical analysis by SEM (Scanning Electron Microscope) was carried out because all samples contained the dark particles and layers (bond lines) at the joint interface. The figure 9 and table 3 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.

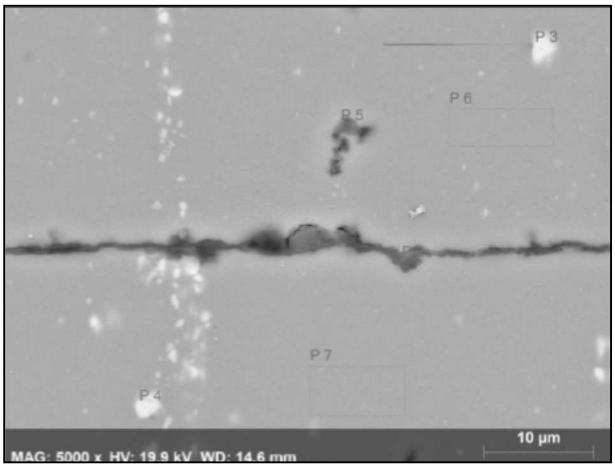

Fig. 9 *SEM analysis*

Tab. 3 *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

5 Discussion

Theoretically, after diffusion welding of homogenous joints, the joint interface should not be visible. But in our research, the joint interface is visible as it is shown in the figures 4 - 8.

According to the recrystallization theory and diffusion welding theory by Kazakov, 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 AlMg3, which led to a rapid formation of magnesium oxide which prevented to form the development of a common joint interface of diffusion welded samples.

The samples I, II and IV were not well welded according to the results of the ultrasonic testing. For the samples III and V the ultrasonic testing shows that the samples were relatively well welded but in comparison to the metallographic examination the samples III and V contain also the dark bond line at the joint interface. A fact is that the bond line of the sample III a V is disconnected and the ultrasonic waves could pass across the disconnected bond line and be reflected by the back wall of the samples III and V. The echoes of sample III and V have a small defect echo (remarked with a red point on the figures 6 and 8) before the back wall echo which might have been caused by the disconnected bond line.

6 Conclusion

The magnesium oxides were formed in the interface of joint during the diffusion 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 the welding process. The ultrasonic testing of the diffusion bonded joints was used in our research for the first time. For better evaluation, calibration and comparison of results of the ultrasonic testing, larger quantities of diffusion bonded joints is necessary to process. Our research team of the Welding Division of the Institute of Manufacturing Technology is going to process a comparison among other developing non-destructive methods (Computed Tomography, Radiographic Testing and testing of electrical properties of welded joints) for the diffusion welding.

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