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Conference Article

Joining of Cu-Mg-Mn Aluminum Alloy with Linear Friction Welding

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Abstract

Al-Cu-Mg-Mn alloy samples were joined together with linear friction welding in two conditions, as is, without pretreatment, and after etching the welding interface. The effect of the welding interface condition was evaluated based on microstructure analysis, microhardness and tensile testing at room temperature. Also, the temperature distribution during welding was estimated with an analytical one-dimensional heat conduction model of the welding process and welding process data.

Keywords: Al-Cu-Mg alloy, linear friction welding, surface preparation, energy input, temperature distribution, microstructure.

1. Introduction

Linear friction welding is the process mainly used for manufacturing blisks made of Ti alloys. Published literature [1, 2, 3, 4] confirms the possibility of getting welded joints of Al alloys with adequate properties.

The group's first experiments on welding Al alloys have shown that the initial stage of welding Al is remarkably different to that of Ti alloys. The welding cycle of the Al alloy differs as it have an "incubation period" which is characterized by low peak values of the shear force Fx.

This observation may relate to the presence of a hard film of Al2O3 on the surface of unprocessed samples. Therefore the presence of an "incubation" period increases the length of the welding process, as well as the energy input, which may adversely affect the structure and mechanical properties of the welding joints of duralumin. A common suggestion for LFW is use of a "hard" mode at high forces with minimum duration.

This work studies of the effect of the surface state on the process of linear friction welding of Al alloy D16T and the properties of its welded joints.

2. Experiments

The samples to be joined had a parallelepiped shape with height 35 mm, which were made of Al alloy D16T (chemical composition of Al–4.1Cu–1.55Mg–0.72Mn–0.24Fe–0.21Si–0.25Zn–0.15Ti (in mass %)).

The welding surfaces of 4 samples following thermal treatment were milled off by 0.1 mm one day before welding (1st series of samples), and 4 samples have been etched in caustic-soda solution just prior to welding (2nd series of samples).

The normal force was set to 16 kN, the amplitude and the frequency of oscillation were 2 mm and 50 Hz respectively. The value of upset, which was used as a criterion for the conclusion of the process, was set to 2.0 mm. After welding the data, which had been recorded by the LFW machine, have been analyzed. The temperature has been calculated using an analytical one-dimensional thermal conductivity model [2].

For the microstructural analysis of welded joint the optical microscope Olympus GX51 was used. For revealing the structure on the surface of the mechanically polished surfaces Keller's chemical agent (1 HF, 1.5 HCl, 2.5 HNO_3, 95 H_2O (ml) was used.

The microhardness measurements were done with a «EmcoTest Durascan 50» testing machine using a load of 1N applied for 10 sec along a line perpendicular to welding interface at a pitch of 0.05 mm.

For tensile testing, flat specimens with dimensions of 12mm×5mm×2mm were machined directly from the welded samples. Tensile tests were performed with the help of the electromechanical testing machine «Instron 5982» at room temperature at a crosshead displacement speed of 1 mm/min.

2. Results and Discussion

<u>**Visual inspection and welding process characteristics.**</u>

During welding a flash developed in the samples. The form and the size of the flash are similar in all samples, irrespective of surface preparation. All samples had shortened axially 3.6 mm after welding.

Shown in Fig. 1 are process data of the welding process for the 1st and 2nd series samples which have considerable differences. Both the length and presence of an "incubation" period are defined by the surface state. The shorter in Fig. 1 (top) cycle has a pronounced "incubation" period lasting

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more than 0.6 seconds, and belongs to samples, which there was a break between surface treatment and welding of more

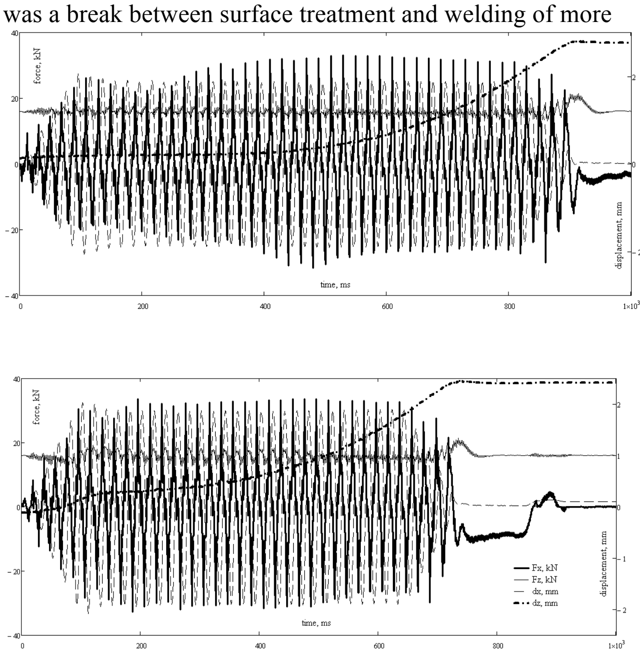


Fig. 1. Process data (force, displacement) for the 1st (top) and 2nd (bottom) series samples.

than a week (1st series). Welding the samples of the 2nd series, does not show a clearly discernible "incubation" period, with a possible length of 0.4 sec Fig. 1 (bottom). While welding the samples of the 1st series, the "incubation" period doesn't appear at all. These differences in the initial phase of the process bring changes to the whole welding cycle, which reduces due to etching of the samples on an average of 0.2 sec on the whole.

Power input and temperature field calculation.

In the analytical model previously presented [2] the energy, spent on heating the samples, has been taken as the difference between the work of the oscillation hydraulic drive and the thermal energy spent on heating the plastic metal which is extruded as a flash during the welding process. The exclusion of the energy spent on heating the plastic material is necessary for modeling the welding of alloys which are based on Ti, as the area where there is a thermo-mechanical effect has short length, and the flash extruded is in the shape of thin ribbons, and its cooling is due to surface heat losses. The flash, in the case of Al alloys, is much wider while being shorter, so the assumption used in the calculation of temperature fields, is that all heat generated by the machine hydraulic drive is spent to heat the samples. In Fig. 2 the power produced during an oscillation cycle, generated by the oscillation drive for all the cases of different surface state samples, as well as the energy accumulated while welding, have been estimated.

From Fig. 2 it is obvious that the 50% difference in power, generated during welding of the 1st and 2nd series, decreases to zero by the end of the "incubation" period. It is interesting to note that the energy input into the etched sample in 0.42 sec after the beginning of welding at 315 J is larger, but the energy input for the whole cycle in this case appears to be less for the 360 J case due to the shorter welding cycle.

The results of the temperature field estimation are shown as thermal cycles in Fig. 3. For the calculations the thermal conductivity coefficient has been assumed to be 1.8

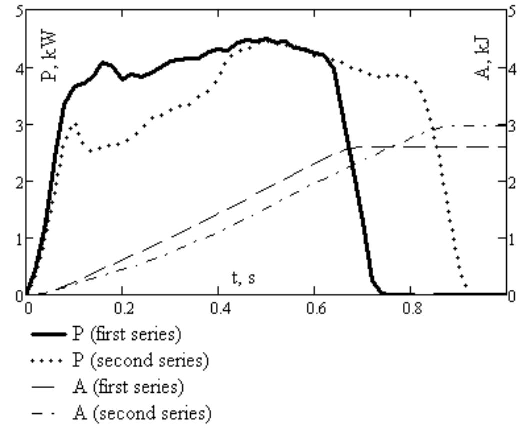


Fig. 2. Power and energy generated during the welding process.

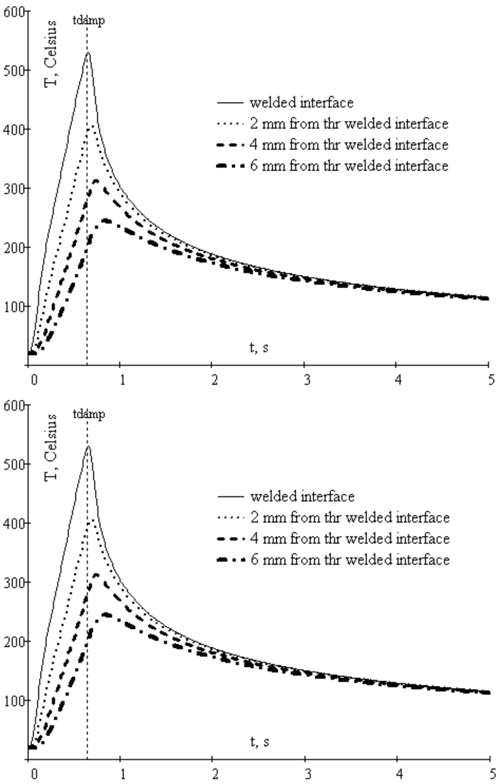


Fig. 3. Thermal cycles for the 1st (top) and the 2nd (bottom) series samples.

W/(cm×K), and the volumetric heat capacity 2.43 J/(cm3×K).

The first etching decreases maximum temperatures reached at the interface and slightly the length of heating the weld. For the case of the milled surface samples, the maximum temperature reached is calculated to be 539 ºC, while for the etched ones it is 510 ºC. The time that the weld is exposed at a temperature of more than 400 ºC is 0.28 sec for the etched samples and 0.4 sec for the milled ones.

The temperature in the cross-section of the joint reaches its maximum value just before the cessation of movement, and by the end of the heating phase it decreases by more than 100 ºC.

Microstructure and mechanical properties of joints.

The width of the weld of the milled samples (1st series) is about 0.4 mm, of the preliminary etched ones (2nd series) about 0.6 mm. The length of the TMAZ is about 1.9 mm. and it does not depend on the quality of preparation of the welded surface (Fig. 4).

Fig. 5 a, b and c show the microstructure of the Al alloy D16 welded with linear friction welding with a milled welding surface.

The parent material zone (Fig. 5, a) has a prominent metallographic texture derived from extrusion. There are big extractions of the preliminary intermetallic phases at the grain boundaries. The volume ratio of the intermetallics is about 15.0 ± 0.4 %. The width of grains varies from 15 up to 45 microns, and their length reaches a few millimeters.

The initially elongated grains turn towards the welding plane in the thermo-mechanically affected zone (TMAZ) (Fig. 5, b). In addition, the near to the edge of the welded sample, the larger the angle of turn. The presence of globular grains is a characteristic of this zone with an average size of 20 ± 2 microns. It should be noted that the size of grains decreases closer to the welding line. Such a transformation of structure in the TMAZ suggest recrystallization. The location of the boundary of the TMAZ corresponds to an estimated temperature of about 400 ºC.

The weld zone has a different response to etching than elsewhere. In this zone grain boundaries are difficult to identify and there are no coarse grains of inter-metallic phases typical of the parent metal.

The metallographic studies of the welded samples which were preliminary etched before welding have not revealed any considerable differences. Microstructural changes are similar to those samples with a milled surface preparation.

Fig. 6 shows microhardness of both series of the welded samples. The average microhardness value for the basic metal is HV 149 ± 1. In the TMAZ there is a slight microhardness decrease up to HV 142 ± 1, which is related to local recrystallization. Closer to the welding line microhardness increases to a maximum at the boundary of TMAZ with the weld line zone, and then decrease rapidly. Microhardness decrease in the weld line zone is related to reaching pre-melt temperatures in the contact zone and, as the result of this, of the dissolution of the hardening intermetallic particles. The minimum microhardness in this area for the samples with the milled surface is HV 139 ± 1, and for the samples with preliminary etching is HV 133 ± 1. It should be noted that preliminary etching leads to a further decrease of microhardness in the weld area.

Tensile tests have shown that the welds have a high strength which is not lower than that of the parent metal. Material flow is characterized by slight hardening and relatively large elongation, reaching in some cases 9 %. The maximum fracture stress is 535 MPa for the samples with a milled surface (1st series) and 540 MPa for the samples with the pre-etched welding surface (2nd series). The tests have shown that the ductility of the samples with the preliminary etched welding surface is higher than of those with the milled surface (Tab. 1). It should be noted, that the break of all samples has occurred in the TMAZ.

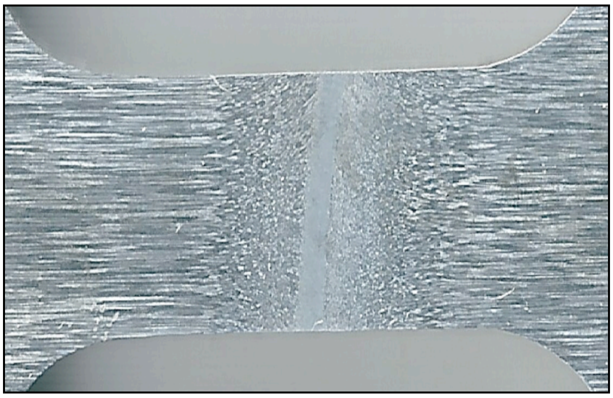
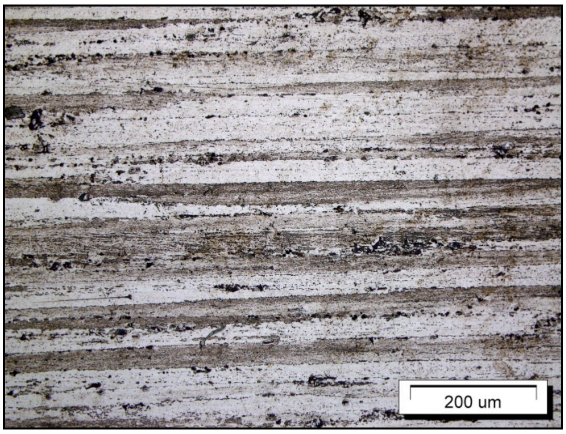
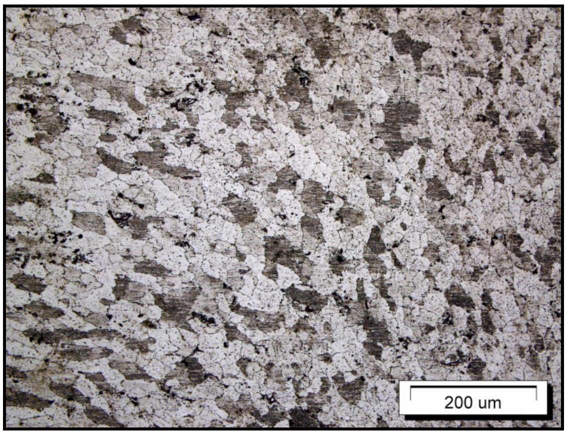


Fig. 4. Macrostructure of welded samples from Al alloy D16.

a)



b)



c)

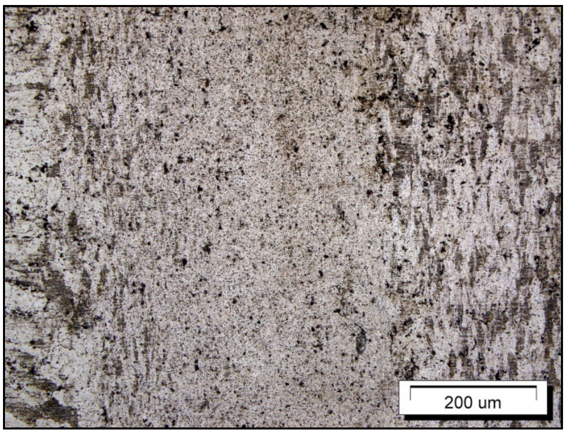


Fig. 5. Microstructure of welded samples of Al alloy D16

Table 1 Mechanical characteristics of the welded samples of Al D16

	Milled samples (1st series)			Etched samples (2nd series).		
	1	2	3	1	2	3
Tensile Strength MPa	524	535	509	531	540	526
Elongation, %	6.9	6.4	5.9	9.5	7.4	8.7

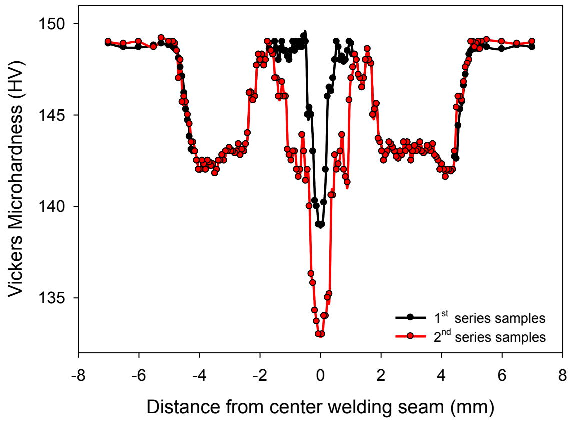


Fig. 6. Microhardness of welded samples of Al alloy D16.

3. Conclusions

1. The process of linear friction welding of Al D16 with an unprepared surface (1st series) starts with an “incubation” period, which is characterized by quite low values of shear forces and power input to the samples applied by hydraulic drive, while there is an absence of shortening. The end of the “incubation” period is obviously connected to the elimination of the Al2O3 film at the wear surface and the appearance of clean metallic surfaces.
2. The length of the “incubation” period depends on the initial state of the welded surfaces. Milling 24 hours before welding decreases process time. Using etching instead just before welding removes the “incubation” period.
3. While the duration of the “incubation” period increases, the duration of the whole welding process increases too along with total energy input. The maximum temperatures reached at the welding interface as well as the time that the welding line is heated increases as well.
4. Tensile testing and metallographic studies show the development of hard sound joints for all types of surface preparation.
5. The introduction of etching procedure does not affect much the length, the structure and microhardness of the TMAZ, but reduces it in weldline.

Acknowledments

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