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Friction Stir Processing of an AlSi6Cu4 cast aluminium alloy

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Abstract

The present paper deals with the Friction Stir Processing (FSP) of an AlSi6Cu4 cast aluminium alloy. The emphasis was placed on the determination of an influence FSP parameters and the torque action on the tool. It was found that an increase in rotational speed of the tool causes a decrease in the torque. Simultaneously, the results showed that an increase in travelling speed of the tool brings about an increase in the torque. The metallographic examination of the processed surface layer of the material has shown that the depth of the layer in which the microstructure was modified by the shoulder action depends to a large extent on the rotation speed and to a lesser extent on the travelling speed.

Keywords: Surface treatment, Friction Stir Processing, die casting aluminium alloy, microstructure.

1. Introduction

The selection of a material with unique structural and functional properties is a key factor in numerous industrial applications, especially in the aircraft and automotive industries. In many cases the requirements for surface properties are different than for the bulk material. Furthermore, failure of components by fatigue, wear or corrosion often initiates at the material surface regions. To improve the properties of the material surface various versatile methods are commonly used including welding technology such as cladding, spraying and laser remelting. However, there is a strong necessity to develop a processing technique that would result in microstructural refinement and homogenisation as well as elimination of defects in the surface layer, leading to an enhanced global performance in service and simultaneously would give an advantage in terms of cost and time of production. Friction Stir Processing (FSP) technology was developed for this purpose.

FSP, a technique derived from the friction stir welding (FSW) [1], is an emerging surface-engineering solid-state technology which provides the ability to thermomechanically process selective locations on the material's surface and to enhance specific properties to some considerable depth. During FSP, the material in the processed zone undergoes intense plastic deformation, mixing, and thermal exposure, resulting in significant microstructural changes. In general, the processed zone is characterized by a recrystallized fine grained structure and uniformly distributed second phase particles. The characteristics of FSP have led to several applications like the formation of superplastic aluminium alloys [2], fabrication of surface composites [3], homogenization of nanocomposite aluminium alloys [4] and processing of metal matrix composites [5].

The AlSi6Cu4 cast aluminium alloy has been subjected to intensive investigations that were concentrated in areas such as the corrosion behaviour of this alloy as a matrix for a composite with 8% vol. of graphite particles [6], oxidation processes [7], microstructure stability at elevated temperatures [8] and modification of microstructure by additions of AlTi5B1 and AlSr10 [9]. Some results of the kinetics of the crystallization processes of AlSi6Cu4 aluminium alloy are also available [10].

The present paper shows the preliminary results of the friction stir processing of this alloy. The emphasis was put on the determination of the influence of FSP parameters on the tool torque and the depth of the layer in which the microstructure was modified by the shoulder action.

2. Experimental procedure

Investigations were carried out at the Instytut Spawalnictwa (Institute of Welding) using a welding machine built on the base of a conventional, vertical milling machine FYF 32JU2 equipped with a LOWSTIR device. The acronym LOWSTIR stands for LOW cost unit for measurements of friction STIR welding parameters. The LOWSTIR system can measure transverse and vertical forces as well as the spindle torque. The measurement of these entities helps to monitor the FSP process. The principle of the application of this device to FSP process was presented in another paper [11]. A non-conventional tool was used in the experiments – a 20 mm diameter shoulder without a pin. The tool was made of high-speed steel (HS6-5-2). The material used during the investigation was a cast AlSi6Cu4 alloy (silumin) in the form of plates 6 mm thick. The plates were fixed to the machine with special grips and then processed. The surface of plates was not cleaned before processing.

Based on prior experience and knowledge the milling machine limitations of the following technological parameters were applied: rotational speeds 112, 560, 900 1400 and 1800 rpm, and traveling speeds 112, 224, 560, 710, 900 and 1120 mm/min.

The microstructural investigation was performed on the plane perpendicular to the process direction (cross-section) by light (LM Leica MEF4M) and scanning electron microscopy (SEM FEI Quanta 200 FEG supplemented by energy dispersive spectrometry (EDS) provided by the EDAX company). For light microscopy the samples were mechanically polished and chemically etched in the Keller's reagent. For SEM the samples were electropolished in a solution of perchloric acid and ethanol (1:5) at 10 V and 12°C for one minute and observed in SEM without etching; the Z-contrast formed by backscattered electrons (BSE) was utilized for revealing constituent phases.

During the process the spindle torque was measured with the use of the LOWSTIR device. The signals were recorded at a sampling rate of 100 Hz on the length of 150 mm.

3. Results and discussion

3.1. Metallography

The typical LM microstructure of the processed material is shown in Figure 1. Two well defined regions (separated by a wide transition zone) could be easily distinguished: the parent material (lower area) and the FSP zone (upper area). The parent material was characterized by the coarse grained structure while the microstructure in the processed zone was modified by the tool action. The modified area resulted in the refinement of the microstructure. The SEM BSE examination revealed characteristic dendrites in the base material (Figure 2). Figure 3 shows a region closer to the surface where the microstructure changes in a continuous way from the typical for the parent material to the refined one adjacent to the surface.

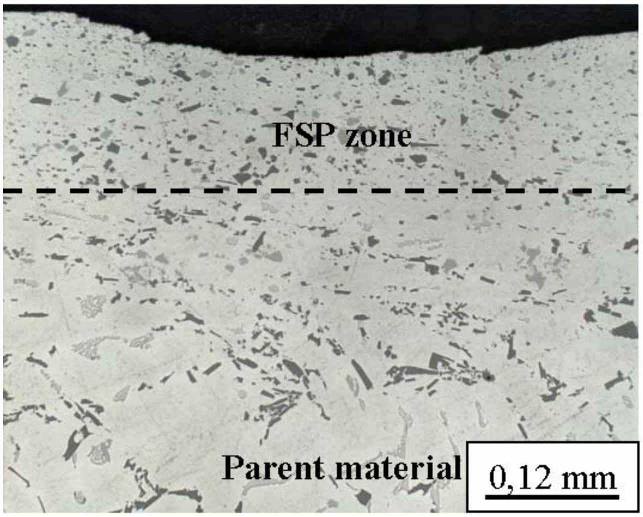

Fig. 1. Typical cross-section of the processed surface layer; light microscope

The constituent phases were characterized by EDS analysis. The alloy is composed of four predominant phases: Si particles, bright Cu-rich particles (probably $CuAl_2$), gray particles with complex composition containing Fe, Si and sometimes Mn (probably phases based on $Fe_2Si_2Al_9$ and $Al_{12}(Fe,Mn)_3Si$ compounds) and the Al solid solution (matrix). However, strong segregation of Cu was revealed in the matrix. The segregation was evidenced by brighter clouds in the SEM BSE images (Figures 2 and 3).

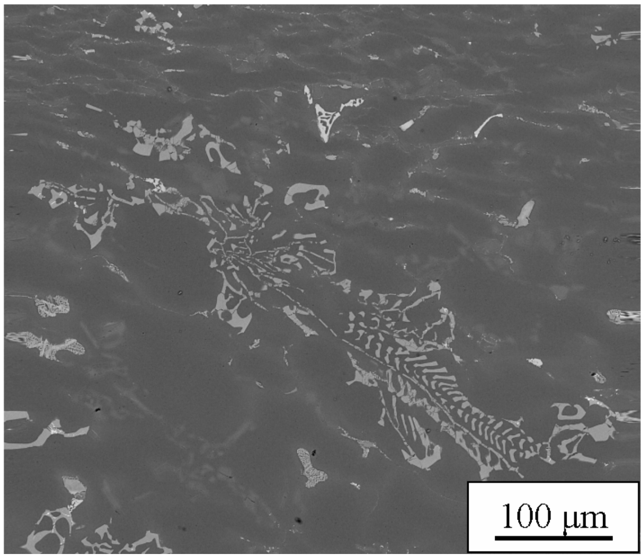

Fig. 2. SEM micrograph of parent material under the processing zone

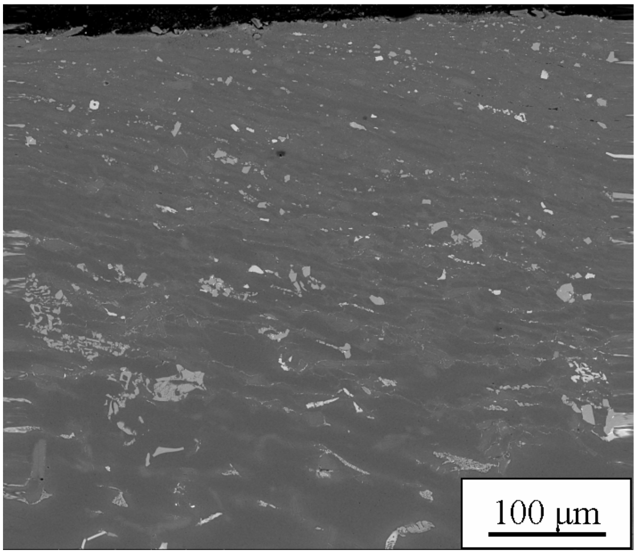

Fig. 3. SEM micrograph of modified surface

3.2. Measurements

It should be emphasized that the signals recorded during FSP are characteristic for the specific tool geometry, parameters of the process, parent material, measurement system and experimental setup. The mean value of the spindle torque was measured by LOWSTIR and calculated from 100 points in the area of the fully stabilized FSP process. The influence of rotational and travelling speeds on spindle torque is shown in Figures 4 and 5, respectively.

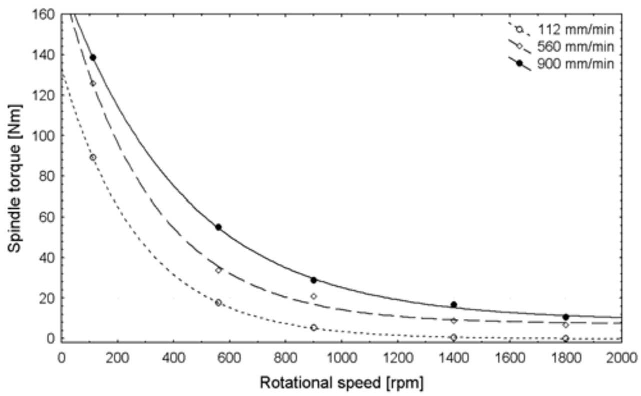

Fig. 4. Influence of rotational speed on the spindle torque

As shown in Figure 4 the spindle torque strongly depends on the rotational speed of the FSP tool. This is due to the fact that the rotational speed stimulates the temperature in the FSP area (modified material) and thus the friction coefficient decreases when temperature increases. However, the torque is not significantly affected by the change in the travelling speed (Figure 5).

The decreasing torque with the decreasing travelling speed at constant rotational speed was evidenced in the literature [12] and may be due to two contributing factors. Firstly, for a constant tool rotation speed and decreasing travelling speed, the volume of material being deformed on each revolution decreases, hence the heat is generated in a smaller volume, and this in turn may lead to slightly higher temperatures and lower flow stress. Secondly, lower travelling speeds will reduce the convective cooling, resulting from slower movement into the relatively cooler material in the front of the tool.

The metallographic examination allowed for evaluating the thickness of the layer under the surface where the microstructure was refined due to the FSP process (penetration depth). The dependence of the penetration depth on the rotational and travelling speeds is illustrated in Figures 6 and 7, respectively.

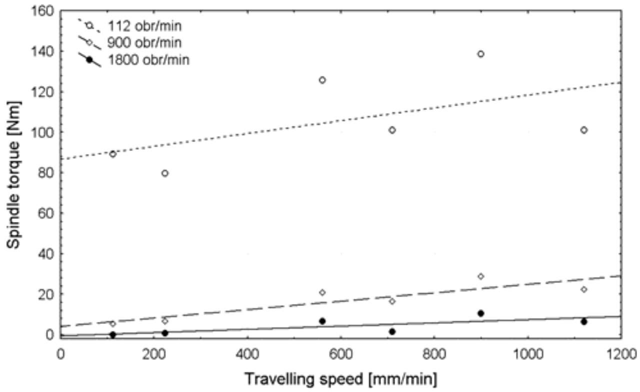

Fig. 5. Influence of travelling speed on the spindle torque

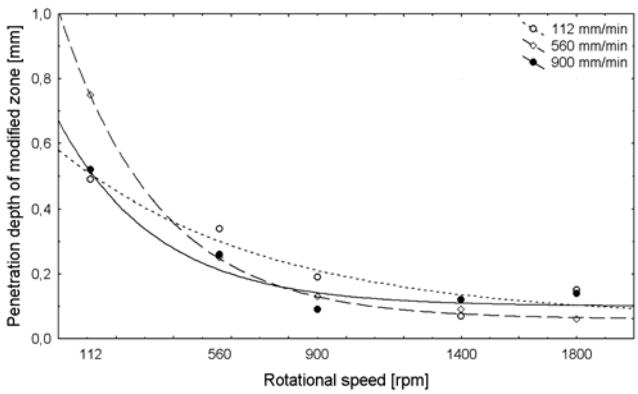

Fig. 6. Influence of rotational speed on the penetration depth

The results shown in Figures 6 and 7 indicate that the rotational speed strongly effected the penetration depth of the modified zone. The decrease in penetration following an increase in rotation speed is due to an increase in temperature within the stir zone. The increase in temperature of modified material causes the strength of it to decrease and the modified aluminium alloy carries lower load. The material undergoes shear faster, and thus the penetration depth of modified zone is lower.

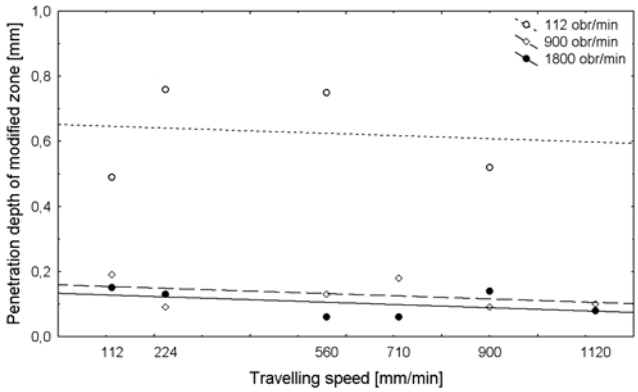

Fig. 7. Influence of travelling speed on the penetration depth

4. Conclusions

The following conclusions can be drawn from the presented investigations:

- the friction stir processing applied to the alloy surface brings about the refinement of microstructure in the near-surface layer;
- the increase of the rotational speed makes the spindle torque acting on the tool decrease;
- the increase of the travelling speed does not influence the spindle torque acting on the tool in a substantial way – only a slight increase was observed;
- the increase of the rotational speed causes the decrease of the penetration depth;
- the increase of the travelling speed has a rather negligible effect on the penetration depth compared to the influence of the rotational speed.

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Badanie procesu tarciowej modyfikacji warstw wierzchnich z mieszaniem materiału odlewniczego stopu aluminium AlSi6Cu4

Streszczenie

W pracy przedstawiono wyniki badań procesu FSP prowadzonego na odlewniczym stopie aluminium AlSi6Cu4. Badania obejmowały określenie wpływu warunków prowadzenia procesu na wartość momentu działającego na narzędzie. Wyniki badań wykazały, że wzrost prędkości obrotowej narzędzia powoduje zmniejszenie momentu działającego na nie. Równocześnie wykazano, iż wzrost prędkości przesuwu narzędzia powoduje wzrost momentu. Z badań metalograficznych wynika, że głębokość oddziaływania narzędzia w dużym stopniu zależy od prędkości obrotowej narzędzia, a w mniejszym od prędkości jego przesuwu.