FRICTION STIR WELDING OF AZ91 MAGNESIUM ALLOY – MICROSTRUCTURE AND MECHANICAL PROPERTIES

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Introduction

Increasing number of magnesium application means that a suitable joining processes are being required. The use of conventional fusion welding often result in formation of defects in welds such as hot cracking, residual stress, porosity, oxide films etc. Friction Stir Welding (FSW), can substantially eliminate or reduce these disadvantages and improve the joint quality. During the friction process heat is generated both due to the friction between the work pieces and the rotating tool shoulder and pin, as well as by the plastic deformation of the material of welded materials. During the FSW process, due to the rise of the temperature, the stir zone (SZ) and thermomechanical affected zone (TMAZ) undergo an intense plastic deformation, which lead to a dynamic recrystallization and reduction in the grain size. These zones are composed of an α-Mg phase with β-$Mg_{17}Al_{12}$ precipitates localized around the grain boundaries. Some research results indicate that the micro-hardness is unevenly distributed in welds and refined grains obtained in SZ lead to increase of micro-hardness, according to Hall-Petch parameter (H_v).

Experimental

FSW process was carried out on the vertical milling machine FYF32JU2 (Fig. 1). During investigation AZ91 magnesium alloy was welded in butt-weld configuration; 6mm thick plates were used. Conventional tool with cylindrical pin was used. The following welding parameters were used: rotational speed ω: 355RPM, welding speed v: 112 and 140mm/min, tilt of the tool: 1,5°. The microstructures of the welds were characterized through light and electron microscopes SEM-EBSD. Temperature measurements were carried out during the welding process with the use of the set of thermocouples (K type), placed in three points in the weld at the AS and RS (Fig. 2b). Numerical modelling of FSW process was carried out. Tensile tests as well as micro-hardness tests (HV0,1) were performed. Places of cutting out of micro specimens are shown in Figure 2a. Hardness test on the cross sections was performed respectively at the distance from the weld face: 1,35; 2,45; 3,55 and 4,65 mm. The Wire Electrical Discharge Machining was used to cut out.

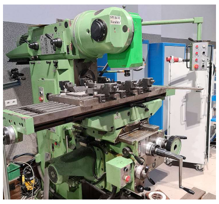

Fig. 1. Weld stand for FSW at Łukasiewicz - IS

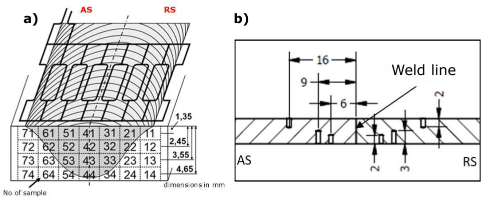

Fig. 2. Position of: a) the microspecimens in weld for microscopic examination and tensile test, b) the thermocouples in the weld: 1 – in the top, 2 – in the middle, 3 – in the bottom

Results and discussion

Based on the result of the light microscopy examination it was find that welds are free from defects and voids. An example of macro and microstructure of joint, made with the welding speed v = 112 mm/min is shown in Figure 3. Due to the complex movement of the tool and the rise of the temperature, which lead to a phenomenon of dynamic recrystallization and reduction in the grain size, material in the stir zone undergoes intense plastic deformation. Some regions with different phase compositions (different content of $Mg_{17}Al_{12}$) were discerned within the weld. These regions were harder than the parent material. In the weld nugget a homogeneous microstructure contains precipitates partly distributed within grain boundaries. Based on the results of SEM the specimen from the nugget characterized the ductile fracture (Fig. 4a), while the specimen from the borderline of the parent material - HAZ, where the material may experience the thermal cycling, the grains are larger and characterized of the brittle fracture (Fig. 4b).

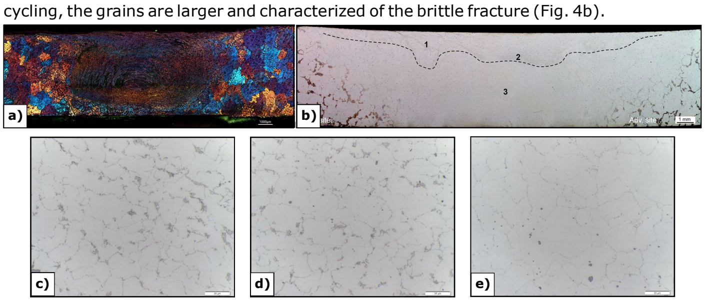

Fig. 3. Results of light microscopy examination of FSW join: a, b) entire weld, c) fragment 1, d) fragment 2, e) fragment 3

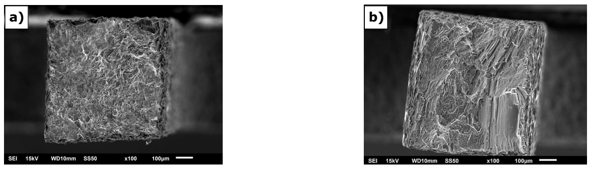

Fig. 4. Results of SEM of speciment no 42 and 74 from Figure 2

Results of the tensile strength (Table 1) showed that the tensile strength of joints rises up to approx 300MPa in the weld nugget and then decreases towards the parent material, whereby the higer tensile strength occurs at the retreating side. The results of the micro-hardness distribution (Fig. 5) showed differences in properties that may affect the performance of the joints. The highest micro-hardness, above 80 HV0.1, was measured directly under the shoulder in the weld nugget and was getting less in direction of the parent material. It was noticed that higher hardness values occur from the retreating side.

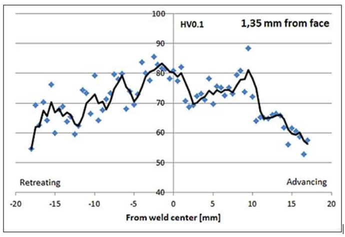

Fig. 5. Hardness distribution: 1,35 mm from the weld face

Retreating Side			Weld center	Advancing Side			Dff [mm]
201±23,2	270±4,5	276±16,2	294±2,3	270±22,9	210±24,1	168±26,9	1,35
162±20,7	235±12,3	297±4,2	277±3,6	272±5,4	195±5,0	133± 8,8	2,45
128±27,0	226±3,0	298±3,2	274±1,6	278±1,7	188±44,7	167± 13,6	3,55
146±51,0	178±29,9	303±5,1	295±0,5	261±5,6	145±30	150± 8,0	4,65

Table 1. Results of the tensile strength Rm [MPa] for specimens in weld. Dff – distance from face of weld

The simulation temperature profiles against the measured temperature profiles at the top, middle and bottom of the workpieces were made. Exemplary results of simulation of the temperature in the middle of weld is shown in Figure 6. From the simulation results that the temperature from the AS is about 300°C and is higher than from the RS. This difference results from the material flow during the friction process. In Figure 7 the relationship between the different microstructural features relative to the temperature profile predicted by the simulation is shown. From simulation results that the temperature under the shoulder may exceed 400°C.

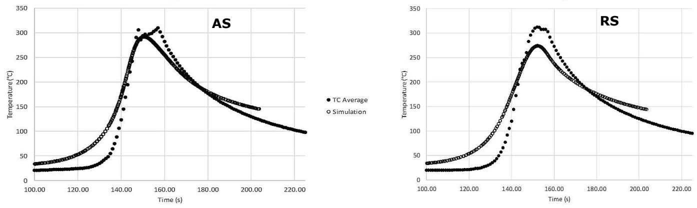

Fig. 6. Exemplary results of simulation of the temperature in the middle of weld

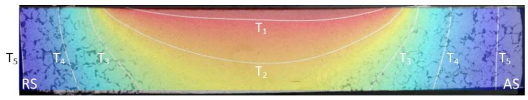

Fig. 7. Relationship between the different microstructural features relative to the temperature profile. Isotherms – T1: 400°C, T5: 250°C with each 25°C increments in between

Conclusions

- During the FSW process, material in the weld undergoes plastic deformation at elevated temperature. It causes dynamic recrystallization and grain refinement with the $Mg_{17}Al_{12}$ precipitates localized around the grains boundaries.
- Reduction in the grain size results in an increase of the tensile strength and microhardness. The specimens from this area characterized the ductility fracture.
- Numerical simulation of the temperature indicates that the temperature in the nugget, under the shoulder, may exceed 400°C.

Acknowledgements

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