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Microstructure and properties of FSW joints of 2017A/6013 aluminium alloys sheets

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ABSTRACT

Purpose: The aim of the studies was to analyse the structure and mechanical properties of FSW joints. Experiment were perform in order to study possibilities to join different aluminium alloys 2017A and 6013. The alloys differ one from the other with respect to chemical composition and mechanical properties especially, therefore the ability to perform the correct joints may be useful for special constructions.

Design/methodology/approach: The joints were produced applying different parameters and temperatures. The microstructure was studied using optical, scanning electron and transmission electron microscopes. The mechanical properties are discussed with regard to microhardness profiles on the cross-sections of the joints.

Findings: No cracks were found in the joints. Weld nuggets were formed in the 2017A alloy which was located on the advancing side during welding. Mixing process of the materials within the joints was observed as a formation of separate regions of the materials being joined. The hardness profiles showed sudden changes of hardness what correlates with structure observations. In the vicinity of the weld nugget higher dislocation density was observed. Lowering the temperature of sheets and welding with intensive cooling caused a decrease in size of the weld nugget.

Research limitations/implications: In the further studies, tensile and bending tests are planned. Moreover, an attempt of explaining the influence of precipitates at the regions boundaries on the fracture process.

Practical implications: Good quality of the joints can be stated on the basis of structure analysis. The chosen parameters of welding can be considered as proper ones.

Originality/value: Comparison of the welding of the alloys2017A and 6013 are not common. The results of studies and conclusions presented in the paper are consecutive data complementing knowledge on FSW of the aluminium alloys. The applied welding parameters ensure good quality of joints with respect to the technology.

Keywords: Friction Stir Welding; Aluminium alloy 2017A; Aluminium alloy 6013; Dissimilar material welding

PROPERTIES

1. Introduction

Joining of the materials of different chemical composition is one the hardest technological operations. In the resulting structure some new phases and solutions deteriorating the properties can be formed that do not exist in the initial alloys. It is especially possible in the application of the high-temperature welding (*e.g.* Gas Metal Arc Welding method [1]). The Friction Stir Welding (FSW) technology is on the contrary a method that does not cause melting of the joined materials and the welding process takes place due to mechanical mixing of the materials with a rotating tool [2]. In a case of but-welding FSW, the sheets being welded form one plane [3, 4], (Fig .1).

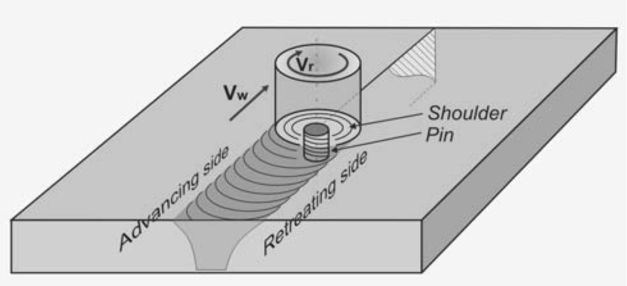

Fig. 1. A scheme of FSW (butt-welding)

A welding line (a path of movement of the tool) can overlap with the line determined by the edges of the joined sheets or it can be dislocated in a direction of one of the materials. The displacement of the welding line is applied usually in the case of welding materials that differ strongly one from another with the melting temperature or mechanical properties [4, 5]. The properties of the joint depend strongly on the welding parameters [6] and the type of the welding tool (pin and shoulder – Fig. 1) [7, 8]. The FSW technology is applied presently in welding light alloys (aluminium, magnesium) as well as copper, steel, composites and dissimilar materials [2, 4, 9].

Explanation of the mechanisms of the formation of the FSW joint is hard due to the complexity of the flow directions of the material and processes taking place in the structure. For example the studies of the aluminium alloys show, various dislocation densities [10]. Various grain size within the weld nugget was also found depending on the linear velocity of the welding [11]. The hardness in the region of the joint can change in many ways [6, 9,12-14] in relative to the original material. The significant difference in the results of the studies result a great influence of the welding parameters and type of tool [3, 7, 15, 16] on the processes taking place in the material during the welding and after its final treatment (*e.g.* aging effects [17]). Even more complications in the structure analysis exist in the joints of a dissimilar materials. In the paper, the results of the welding experiments, structural studies performed with the aid of various observation techniques and microhardness distribution profiles with respect to the FSW joint of the aluminium alloys with different composition and mechanical properties are presented.

2. Experimental method

The material used in this study are aluminum alloys 2017A and 6013 in the form of sheets of thickness of 6mm. The composition of the alloys was following: 3.9% Cu, 0.6% Mn, 0.6% Mg, 0.4% Si balance Al in wt%, and 1.1% Cu, 1.0% Mg, 0.7% Mn, 0,8% Si, 0,3% Fe balance Al in wt%. Butt joints were made parallel to the rolling direction at rates of rotation 450 rpm and linear velocity of the tool 224 and 280 mm/min. The welding process was performed with a conventional tool: pin with a diameter of 8 mm, shoulder with a diameter of 25 mm, an angle between tool shoulder and the surface of the welded sheets was 1.5°. Line of welding was shifted 2 mm into 6013 plate. The welding was carried out at room temperature. In some cases intensive cooling of the surface of the sheets, which were earlier cooled down to about 259 K (-14^{o}C), was implemented. The cooling was performed by pouring granulated dry ice (CO_2) on the surface of the sheets being joined. The samples were investigated in the after-welding state (the samples stored at the temperature of 243 K (-30^{o}C)). The studies of the mechanical properties were carried out to determine the hardness profiles μHV0.1 at a cross-section at a distance of 2.5 mm from the surface (face of weld). The microstrucuture investigations were conducted using an optical microscope OLYMPUS GX51 with Nomarski differential interference contrast, transmission electron microscope (TEM) CM20 with acceleration voltage 200 kV and scanning electron microscope (SEM) Philips 525M. The microscopic observations at the optical microscope were performed on the cross-sections that were ground and polished mechanically, and then etched with 2 ml HF, 4 ml HNO_3, 94 ml H_2O solution. The TEM observations were carried out from the weld nugget and the regions close to the thermo-mechanically affected zone. The samples for TEM analysis were jet-electropolished in a solution consisting of 1/3 nitric acid and 2/3 methanol at temperature of 248 K (-25^{o}C). The SEM studies were conducted on polished surface in the cross-section of the joints.

3. Results and discussion

Figure 2 presents the hardness distribution profiles of the welded samples produced with (280L) and without intensive cooling of the sheet surfaces (280) at the following parameters: rotational velocity of 450 rpm, linear velocity of 280 mm/min. The microhardness profiles of the sample welded with the intensive cooling show considerably higher hardness of the weld on the side of 2017A and also slightly raised hardness in the region affected by the tool.

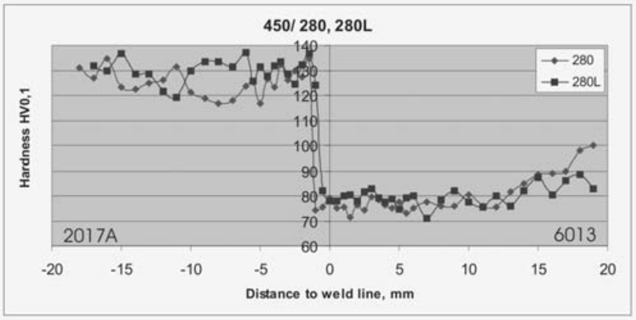

Fig. 2. Distribution of microhardness on a cross-section of weld joint – 450 rpm, 280 mm/min, the after-welding state, L – cooling

Similar profile of the hardness distribution was observed in the welds produced at the linear velocity of 224 mm/min, however in this case a smaller influence of cooling on the hardness is noticed. A displacement of the welding line in the direction of the alloy 6013 (material with smaller hardness) is also visible on the hardness profiles. Similar values of the hardness of the 6013 alloy were presented in [4] although a distinct drop in the heat affected region (about 7 mm from the welding line) is visible on the hardness distribution profile. Additionally, the studies on the 6082 alloy presented in [18] show a decrease of the joint hardness in comparison with the original material, what is in agreement with findings for the 6013 alloy.

The structure analysis of the joints performed by means of the optical microscopy show that mixing of the joined materials (within the weld) depend mainly on the formation of the adjoining regions, each of the different material. The microstructure of the joint on the advancing side produced at the rotational velocity of 450 rpm and linear velocity of 224 mm/min is presented on Figure 3. The brighter regions (three of them are pointed by arrows) consist of the 6013 alloy. The matrix consists of the 2017A alloy. The weld nugget (pointed by arrow on Figure 4; upper part, 6013 alloy) is made of the 2017A alloy because the alloy was probably placed on the advancing side regarding the resultant movement of the tool. Such arrangement of the structure of the studied joints explains the sudden changes of the hardness in the cross-section (Fig. 2) and the possibility of occurrence of local drops of the hardness on the advancing side. The borders between the regions are clearly visible due to presence of very fine precipitates. They do not form, however, any continuous layer.

The bands visible on Figure 3 were also analysed by scanning electron microscopy. One of the bands of the 6013 alloy in the matrix of 2017A alloy is presented on Figure 5. The EDS analysis of the chemical composition of the precipitates proved the particles are composed of Al, Si and Al, Mn, Fe within the band of the 6013 alloy. These phases are probably the typical ones for the alloys of 6xxxx series, *i.e.* α-$Al_{12}Fe_3Si$ lub β-$Al_9Fe_2Si_2$ [19]. In the rest of the sample (2017A alloy), the precipitates consists of Al, Cu and Al, Mn, Fe, Cu. Besides, the analysis of the weld nugget proves the presence of the structure and particles characteristic for the2017A alloy.

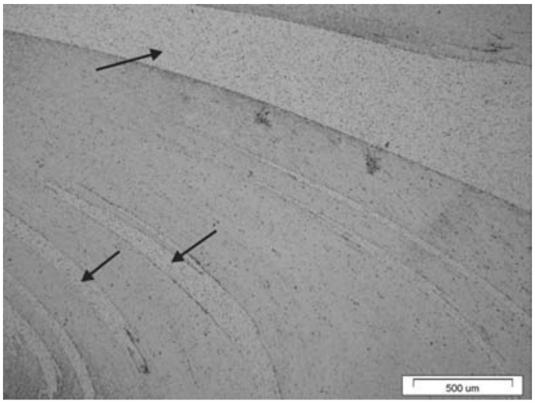

Fig. 3. Microstructure of advancing side of FSW joint – 450 rpm, 224 mm/min (light microscopy)

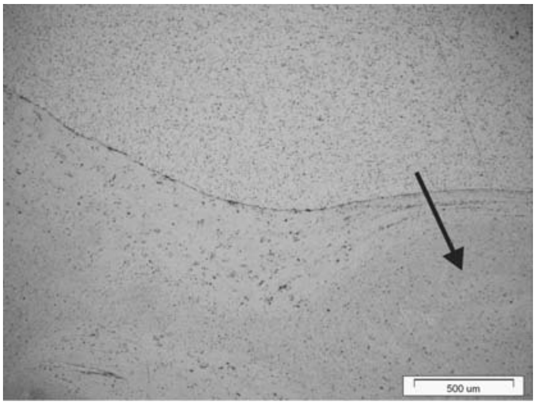

Fig. 4. Microstructure of advancing side/center of FSW joint – 450 rpm, 224 mm/min (light microscopy)

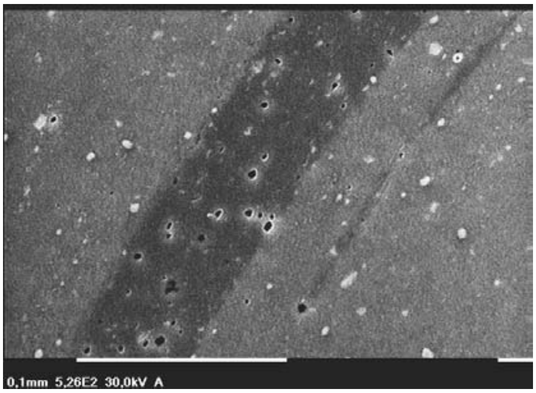

Fig. 5. Microstructure of advancing side of FSW joint – 450 rpm, 224 mm/min (SEM)

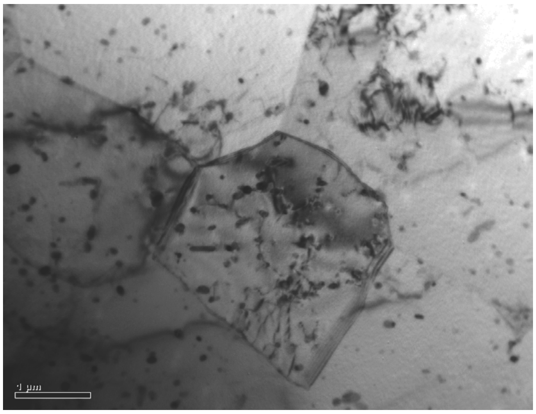

Fig. 6. Microstructure of the center of the joint – 450 rpm, 280 mm/min L (TEM)

The transmission electron microscopy investigations allowed to determine the grain size within the weld nugget at 4 μm. The studied joint was made at the parameters of 450 rpm, 280 mm/min with application of the intensive cooling. The grain refinement in the region results from a dynamic recrystallization that proceeded during the welding process [8, 20]. Moreover, an increased dislocation density interacting with the precipitates was found there (Fig. 6). Such kind of phenomena can be observed in the joint structure regardless the increased temperature during the FSW welding [10].

4. Conclusions

Application of the friction stir welding technology allows to obtain the good-quality welds of the 2017A and 6013 alloys. The structure of the joints is composed of the regions formed from both materials separately. It has its representation in the hardness distribution profiles that were performed on the weld cross-section. The weld nugget was formed from the 2017A alloy, which was welded on the advancing side of the tool. The decrease of the temperature prior to welding and the intensive cooling during the process causes reduction of the size of the nugget and domination of the 6013 alloy in the joint (6013 alloy was located on the retreating side of the joint). A certain grain refinement is observed in the weld especially in the weld nuggets and the adjacent regions.

Acknowledgements

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