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DETERMINATION OF MICROSTRUCTURE OF THE FSW PROCESS

Ph.D. Milan Vukčević
Ph.D. Nikola Šibalić
Ph.D. Sreten Savićević
Ph.D. Mileta Janjić
University of Montenegro
Faculty of Mechanical Engineering
Džordža Vašingtona bb, 81000 Podgorica
Montenegro

ABSTRACT
This paper provides the research of the influence of geometric and kinematic parameters on the microstructure of welded joint of aluminum alloy 6082-T6 obtained through the Friction Stir Welding (FSW) process. The experiment parameters were welding speed, rotation speed, angle of pin slope, pin diameter and shoulder diameter. On the obtained welded work pieces the determination of micro structural zones were carried out.
Keywords: shoulder, pin, microstructure, impact toughness, FSW

1. INTRODUCTION
Tools used in the FSW process are cylindrical and consisted of two concentric parts, which rotate at high speed. Part of the tool with larger diameter is called the shoulder, while the part with smaller diameter is called the pin. Tool and work pieces that are welded are shown in figure 1 [1, 2, 3, 4, 5].

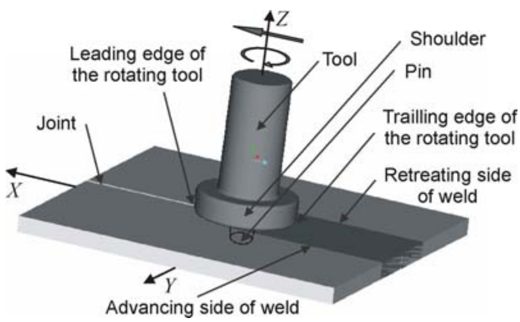

Figure 1. Scheme of FSW process

6082-T6 alloy belongs to the group hardly welded alloys by conventional methods due to poor hardening and high porosity in the welding zone, so the effect occurs due to dissolution and coarsening of hardening phases. For that reason, welding of aluminum alloy using Friction Stir Welding process represents a major challenge for researchers.
Micro structural delineation of the four zones of the cross section of welded joint is shown in figure 2 [1].

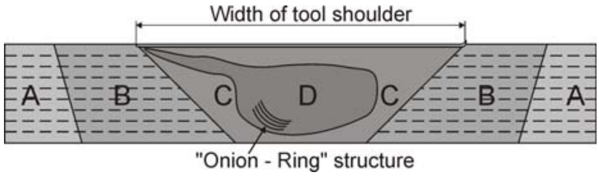

Figure 2. Various microstructural regions in the transverse cross section of friction stir welded material. A - unaffected material or parent metal, B - heat affected zone - HAZ, C - thermo-mechanically affected zone - TMAZ, D - "weld nugget" zone - NZ [1]

2. EXPERIMENTAL PROCEDURE

In order to determine the influence of geometric parameters of the tool on the micro structural changes, the experimental research of welding of aluminum alloy 6082-T6, thickness of 7,8 mm was carried out. The family of tools where geometrical parameters were varied was adopted for welding of aluminum alloy sheet. The general image of the family of tools for the FSW process is shown in figure 3.

Based on preliminary researches, the multifactor orthogonal plan with varying of factors on two levels, and repetition in the central point of plan n_0=4 times is adopted. For input values, factors of the welding regime are adopted: X_1=v mm/min (welding speed), X_2=ω rpm (rotation speed of tool) and geometrical factors of tools: $X_3=\alpha^o$ (angle of pin slope), X_4=d mm (diameter of the pin) and X_5=D mm (diameter of the shoulder). Levels of variation of input factors are adopted and given in Table 1 [3].

Figure 3. Tool with accepted dimensions and parameters D, d and α

Table 1. Levels of variation of input factors [3]

Input factors	Upper level	Lower level	Basic level
X_1	200	80	125,00
X_2	1 000	630	800,00
X_3	5	3	3,87
X_4	7	5	5,92
X_5	28	25	26,46

Based on the adopted values of X_3, X_4 and X_5, the set of nine tools is made, and shown in figure 4.

Figure 4. Set of tools made according plan of experiment

Figure 5. Research site: 1 - auxiliary equipment, 2 - work pieces of aluminum alloy 6082-T6, 3 - tool for FSW

The process of conducting the experimental researches is shown in figure 5, and figure 6 presents the welded work pieces for the 36th point of the experimental plan.

Figure 6. Welded work pieces [3]

3. DETERMINATION OF MICRO STRUCTURAL ZONES

The process of metallographic, mechanical specimens preparation is done through a series of successive operations: cutting (sampling), roughing, mounting, grinding and polishing. Chemical analysis of specimens obtained from cuts of work pieces welded by FSW process, is carried out with the appropriate reagent. The reagent is prepared by measuring of 1,3 ml 40 % HF hydrochloric acid in the gauge and gently mixed with 200 ml of distilled water into a suitable glass container. In this way, the reagent is ready for use.

Examination of macrostructure and microstructure is carried out by methods of light microscopy. Method of light microscopy was used for providing recordings for all specimens, for all points of the experimental plan in elected positions. The aim of metallographic research is to identify the various defects that occur during the FSW, as well as the identification of micro structural changes. Figures 7 and 8 shows the macrostructure of the specimen with the positions of micro structural zones.

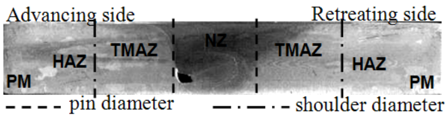

Figure 7. Macrostructure of the specimen No. 2

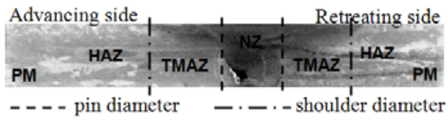

Figure 8. Macrostructure of the specimen No. 31

Characteristic structural zones of FSW can be clearly identified from recorded images of macrostructure, those zones are: unaffected material or parent metal, heat affected zone - HAZ, thermo-mechanically affected zone - TMAZ, and so called "weld nugget" zone - NZ. The images clearly show defects that are present for certain points of the experimental plan. That is so called "tunnel" effect on the advancing side, as a result of insufficient transport material around the pin. This defect is one of the density errors, which can be detected by radiographic images, which are mostly incessant. This error can be avoided by proper choice of geometrical parameters of tools and kinematic parameters of the process. Based on the macrostructure images for certain specific positions, images of microstructure are recorded, which provide a clearer view of the observed structure of welded joints, as well as the grain size. Figure 9 shows the microstructure of the unaffected material. Figure 10 shows the microstructure of heat affected zone - HAZ, while figure 11 shows the microstructure of the transition between the heat affected zone and the zone of thermo-mechanical effects for the center point of the experimental plan No 35.

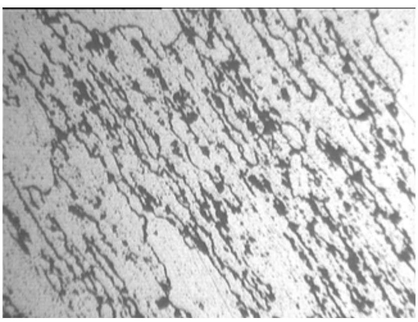

Figure 9. Microstructure of the unaffected metal

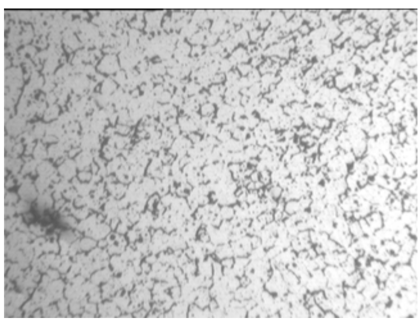

Figure 10. The microstructure of HAZ – TMAZ

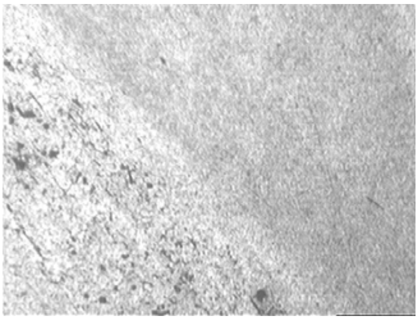

Figure 11. The microstructure of HAZ – TMAZ

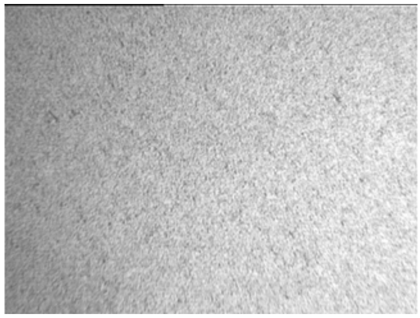

Figure 12. Microstructure of the NZ

When examining the microstructure, one can clearly identify the transition between the zone that was affected with deformation from tools and the unaffected material zone. The material which was deformed by FSW process, shows a well-turbulent grain structure, as well as materials in the vicinity of the heat affected zone - HAZ, which gives the proper arrangement of grains. In the mixing zone, a very fine recrystallized grains are present, due to the large deformation of material and high temperature during the FSW process. Microstructures within the "weld nugget" zone indicates dynamic recrystallized grains, which are much smaller than with the unaffected material, where the larger size grains are present. Dynamic recrystallized "weld nugget" zone is shown in figure 12, for the center point of the experimental plan No 33.

4. CONCLUSIONS

The experimental researches carried out successful welding of aluminum alloys 6082-T6 with the thickness of 7,8 mm, using the FSW process and it was determinate that the quality of weld depends greatly upon tool dimensions (shoulder diameter, pin diameter, and the angle of the pin slope) as well as regimes of welding (welding speed and rotation speed).

Testing the macrostructure of FSW specimens, the existence of several micro structural zones was determined: Unaffected Material Zone, Heat Affected Zone - HAZ, Thermo-Mechanically Affected Zone - TMAZ and "Nugget" Zone - NZ. Microstructure obtained on advancing and retreating side are quite different: on the advancing side, the sharp border between the thermo-mechanically affected zone and stirred zone has appeared, and on the retreating side there is a continuous change between the two regions.

5. RERFERENCES

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