Numerical investigation and prediction of grain Size in different friction stir welding areas of AA6061 Aluminum alloy

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ABSTRACT

Friction stir welding is a solid-state bonding technique based on two factors, a pressure greater than the material yield stress and large plastic deformation. The final joint between parts takes place in different welding geometries by using these two factors. The grain sizes in the weld areas are influenced by recovery, recrystallization, and grain growth. In current research using an analytical-numerical method based on finite element simulation of friction stir welding of AA6061-T6 alloy, the grain sizes in various welded areas have been predicted. The finite element simulation has been performed based on the Coupled Eulerian-Lagrangian approach using ABAQUS software and the results have been verified by experiments. The predicted results were in good agreement with the experimental results. Due to the concentration of heat and plastic flow in the central region of the weld, the stirring region had the most microstructural changes and the grain size in this region decreased more sharply than other different areas of the weld. As the rotational welding speed increases, recrystallization phenomena in the central weld area increases. With increasing the translational welding speed, grain size increased in different welding areas. This increase occurred more severely in the central area of the welded joint.

KEYWORDS

Friction stir welding, Grain size, Finite element, Weld Zones, Aluminum Alloy.

1. Introduction

Among the existing techniques used to connect parts, welding can be considered the most widely used and popular technique [1]. This connection method has special and significant advantages, but it also has disadvantages. Due to local melting problems created during traditional welding (fusion welding), the mechanical quality of the joint typically declines significantly [2]. The idea of using techniques that can be used to create the connection in the absence of melting materials, has led researchers to invent solid state connection processes [3]. In the solid state connection method, due to two pressure factors and large plastic deformations, the final connection is formed in two parts [4]. Friction stir welding (FSW) is a solid state bonding technique that can be used to weld homogeneous and non-homogeneous parts [5]. The main purpose of the present study is to predict the grain size and its evolution in different areas of the weld section.

2. Numerical model

A numerical method is used to approximate the solution of partial differential equations as well as to solve integrals. The basis of this method is the complete elimination of differential equations or their simplification to ordinary differential equations that are solved by numerical methods such as Euler. In solving partial differential equations, the important issue is to achieve an equation that is numerically stable, meaning that the error in the initial data while solving is not so great as to lead to incomprehensible results. There are several advantages and disadvantages to this approach, and the finite element method is one of the best. Dimensions and parametric conditions of the simulated FSW process were based on experimental working conditions performed by Wu et al. [6]. Thus, the final dimensions of the workpiece according to the experimental conditions were considered equal to 100 × 60 × 6.85 mm, which was divided into two separate parts. According to the experimental work, the rotational speed of the instrument was considered to be equal to 156 rpm and the forward speed was equal to 0.42 mm / s. The instrument used in the present study was considered to have a shoulder diameter of 25.4, the pin diameter of 6.35 and the pin height of 6 mm in accordance with the experimental work. The finite element model of the tool and work-piece is shown in Figure 1.

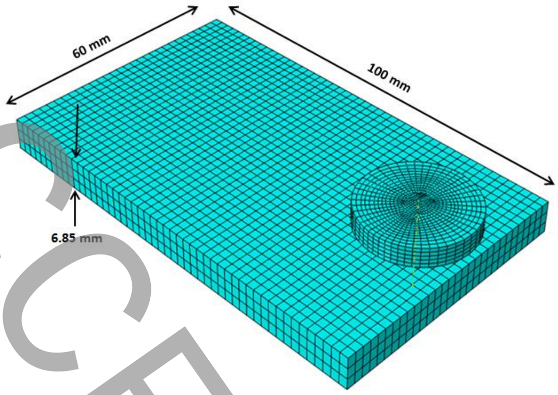

Figure 1. Finite element model with geometric dimensions.

3. Results and Discussion

3-1. Temperature and strain rate

Temperature simulations in the FSW process during the penetration phase, the settling phase and the turbulence phase for AA6061-T6 aluminum alloy were performed according to the laboratory conditions and the temperature history of different element nodes of the work-piece based on different distances from The welding center was registered. Figure 2 shows the temperature distribution contour in the work-piece after stabilizing the temperature situation in different welding areas.

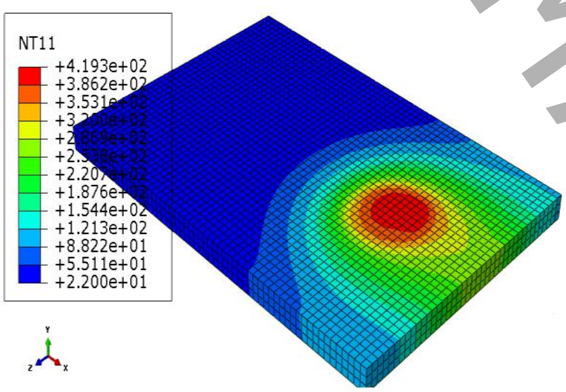

Figure 2: Countor of temperature in numerical simulation (°C)

3-2. Grain size in welding areas

Strain, temperature term and strain rate at different points and nodes were calculated based on the results of numerical simulation. Then, by placing the data obtained from numerical simulation in relation (1), the grain size of different welding areas was calculated.

$$D_{CDRX} = C\,\varepsilon^{J}\,\dot{\varepsilon}^{k}\,D_{o}^{h}\,\exp\left(\frac{-Q}{RT}\right) \quad (1)$$

The results of grain size in the weld cross section of the present study and the results of the experimental study of Wu et al. [19] are shown in Figure 2 and Figure 3 of the percentage error of numerical and experimental results across the weld cross section.

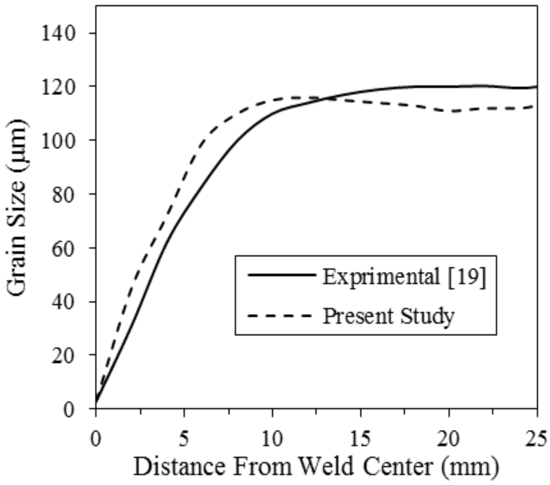

Figure 2: Particle size under simulation and experimental conditions

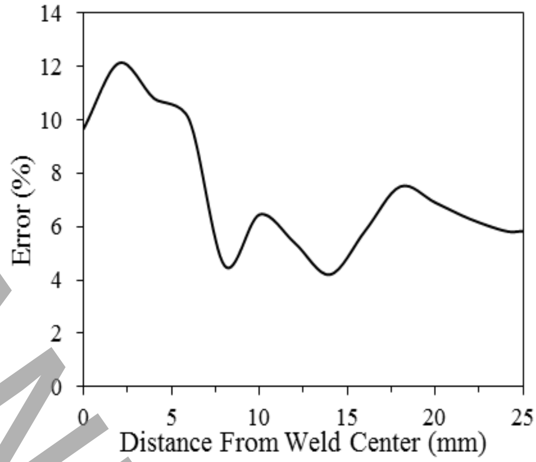

Figure 3: Percentage of error between numerical and experimental results

3-3. Effect of rotational speed

In order to investigate the effect of tool rotational speed on grain size in FSW welded specimen cross section, five different rotational speeds were used for the tool. Numerical simulation was performed according to the trend presented in the previous sections for all five models and the grain size in different areas of the weld section was calculated using the present numerical analytical model. Figure 4 shows the grain size distribution for welding specimens with different tool rotational speeds.

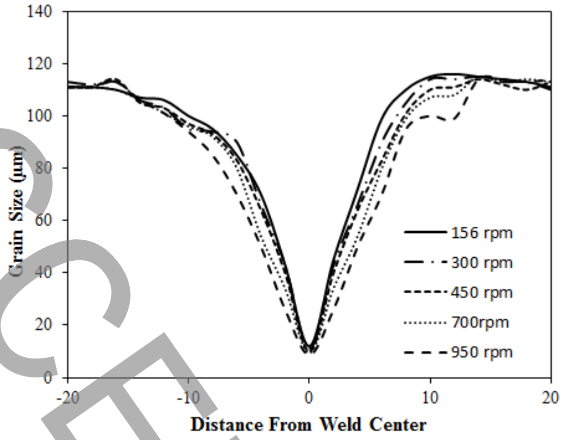

Figure 4: Grain size at different rotational speeds

3-4. The linear velocity effect of the tool

In order to investigate the effect of tool linear velocity on grain size in the section of the welded sample, five different linear velocities were used for the tool. Figure 5 shows the grain size distribution for welding specimens with different welding speeds.

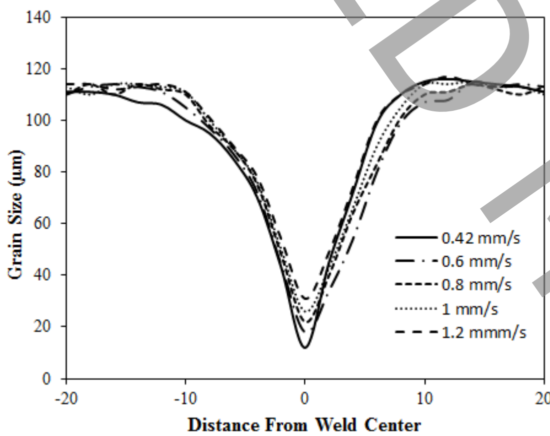

Figure 5: Grain size at different translational speeds

4. Conclusion

Grain size prediction of different welding areas in FSW process of AA6061-T6 aluminum alloy was investigated using a new numerical analytical model. The temperature, strain and strain rate were calculated by numerical simulation with ABAQUS 2017 software. Then, using the analytical relationships of the automatic cell model and subroutine writing, the grain size in different areas of the weld section was calculated. The results of the research can be summarized as follows:

• Using the present numerical analytical model, the FSW process can be predicted with a small percentage of error in the grain size of different areas of the welding section.

• The smallest grain size occurred in the central welding area due to the high temperature, strain and strain rate in this area, which causes complete dynamic recrystallization in this area.

• Due to the increase in material flow and higher temperature in the AS section, the amount of grain size reduction in this area is greater than the RS area and the particle size in this area is smaller.

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