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Process Modelling of Friction Stir Welding of Aluminium alloys AA6061 and AA5083

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Abstract: Friction stir welding (FSW) is a solid-state joining technique that is used to weld many kinds of materials, such as aluminium, magnesium and titanium alloys and even plastics. DEFORM-3D software was used to simulate the FSW process from the experimental research. Input parameters of the tool was obtained from the previous experimental data. The process parameters involved were 700 rpm and 1400 rpm for rotational speed while for transverse speed, settings of 80, 60, and 40 mm/min were applied. The simulations used input parameters that resulted in maximum, medium, and minimum tensile strength in actual experiments performed. Workpiece is defined as rigid-visco plastic material and tool is modelled as rigid because the yield strength of tool material is much higher compared to workpiece materials. The workpieces were meshed with 32000 elements and the tool was meshed with 8000 elements. Remeshing was done at the workpiece and tool contact area along the welding direction to obtain high result accuracy. Boundary conditions and heat transfer coefficient for this FSW process were obtain from previous research paper. Temperature, effective strain, and effective stress distribution during the process on the workpiece were analysed in this study since it cannot be retrieved from the experiment. The results from simulations for different rotational speed and transverse speed showed uneven temperature distribution on the workpieces. These results are not reached agreement with previous research and effected the effective strain and stress distribution. It was observed that caused by deficiency in simulation setup especially for boundary condition setup.

Keywords: Friction Stir Welding, DEFORM-3D, AA6061, AA5083, Temperature Distribution, Effective Strain, Effective Stress

1. Introduction

Metal joining methods have been discovered thousands of years ago, but forge welding by blacksmith is the only form of welding during this period. At the end of 19th century, variety of entirely new welding processes are appeared [1]. The method eventually evolved rapidly year by year until today. Welding can be defined as fabrication process where two or more similar or dissimilar materials are fused together to join permanently with or without the present of heat, filler material or external

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**Corresponding author: shazarel@uthm.edu.my* pressure [2]. Now, there are more than 75 types of welding processes available for manufacturer to choose by considering the recent developments in welding technology. The explanation why there are so many processes is that each process has its own different advantages and disadvantages that make it more relevant to a particular application [3].

Welding process is classified by two: fusion welding and solid-state welding. Fusion welding is the method by which the filling surfaces of parent materials are melted down with the filler material to form the weld bead. Arc welding, gas welding and intense energy beam welding are some examples of fusion welding. Solid-state welding is joining two work pieces under a pressure by providing a close contact between them and at a temperature essentially below the melting point of the parent material [2].

Friction stir welding (FSW) one of the examples of solid-state welding. It was originated from The Welding Institute (TWI) in 1991. FSW usually applied in fabrication of parts for aerospace, automotive, electronic housings, railway coolers, shipbuilding, heat exchangers and nuclear waste containers. Friction stir welding produce highly refined, equiaxed grains that improved the material properties such as strength, ductility, and corrosion resistance. The process requires rotating tool that plunged into the material surface to be processed and the tool moves through the surface to be processed as shown in Figure 1.1. As the rotating tool progresses, the heat produced by friction is used to plasticize the material around the processing area and the grains are broken down by the plastic deformation action of the rotating tool. FSW has greatly impacted the welding industries due to the ability to join material with thickness ranging between thin sections to a very large thickness with high weld quality [2]. Numerous studies had been carried out by the researcher to improve the ability of friction stir process.

In this study, FSW process needs optimization on the parameter for welding two dissimilar aluminium alloys. The tensile strength of the welding joints is the main factor of good weldability and efficiency between two alloys. High quality of joints that show less defect and mechanical failure are required in the manufacturing industry. Temperature and stress distribution can affect the strength of weld joints. Accurate simulation about tool surface temperature is necessary to discover the effect of temperatures on weld strength. Fusion joints can be replaced by FSW to achieve the functionally graded materials that can significance the cost and weight savings. By applying more FSW process the industry, it will help saving the cost and improve the quality of the product. Numerical simulation on the FSW process can saving cost in research area without use the actual material and obtain information that cannot be retrieved from the experiment.

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2. Simulation Details

2.1 Geometry Modelling

DEFORM 3D numerical modelling was applied to run the simulation in order to obtain the temperature, stress and strain distribution in FSW process of AA6061-T6 and AA5083-H116. The plates of aluminium alloy of AA6061 and AA5083 were designed with dimension of 65x50x4 mm for the FSW process on dissimilar materials. It will be joined together as butt joint for this process. The welding tool was made from mild carbon steel and the hardness of the tool after heat treatment is 53-55 HRC. The design parameters of the tool are cylindrical pin with diameter of 2.5 mm, shoulder diameter of 18 mm and pin length of 3.5 mm [4]. The workpieces were meshed with 32000 elements while the tool was meshed with 8000 elements. Remeshing required at the workpiece and tool contact area to obtain high result accuracy as shown in the Figure 1. Higher number of elements offers enhanced precision and increased resolution in geometry and detailed field variables such as strain, temperature, and damage. Nevertheless, when the number of nodes increases, the computational time for simulation increases significantly.

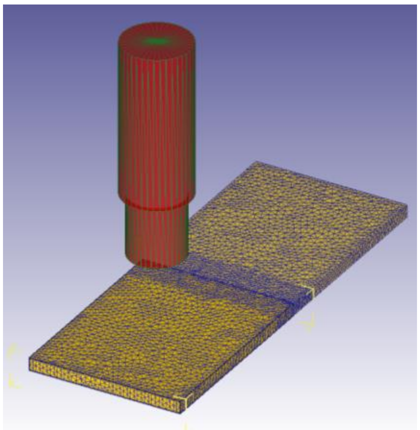


Figure 1: Meshing on workpieces and tool

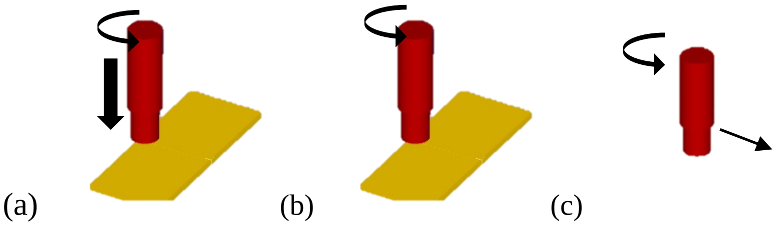


Figure 2: Schematic representation of sequence of FSW process (a) First stage: Plunging, (b)Second stage: Dwelling, (c)Third stage: Welding

Simulation process was divided into three stages as shown in the figure 2. To constraint the rigid body motion of workpiece and to define various heat transfer modes, various boundary conditions are required. Since rotational and travel velocities have been defined on the tool, all degree of freedom of workpiece needs to be constrained. Workpieces bottom face is arrested along Z axis direction because material flow take place in XY plane. Therefore, side faces of the aluminium plate in X and Y directions are constrained. Convective heat transfer coefficient of 0.02 N/s/mm°C is defined between free surface of workpiece-tool and environment. A constant interface heat transfer coefficient of 11 N/s/mm°C has been defined for workpiece-tool and workpiece-workpiece contact surface [5]. Heat exchange with environment have been defined for workpieces and tool with environment temperature of 20°C.

2.2 Material model

Appropriate choice of material model is important for accurate solution during simulation. Chosen material from DEFORM material library must undergoes from solid to viscous state to define flow stress value for a wide range of strain, strain rate and temperature. Flow stress is defined for a range of strain, strain rate and temperature.

$$\bar{\sigma} = \bar{\sigma}(\varepsilon, \dot{\varepsilon}, T)$$

Where, $\bar{\sigma}$ is flow stress, ε is strain and $\dot{\varepsilon}$ is strain rate.

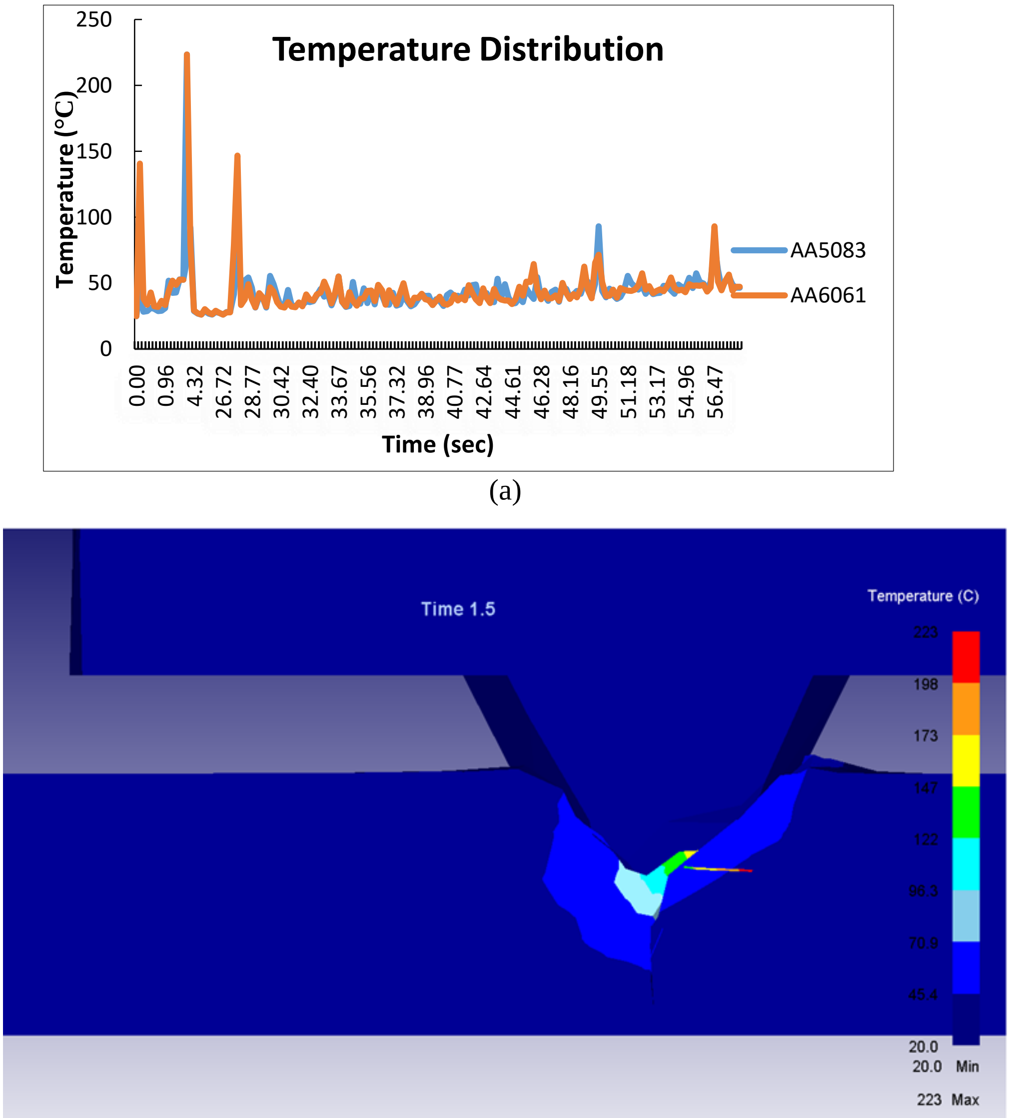
2.3 Frictional model

Contact area between tool and workpieces is quite complex to understand due to lack of experimental evidence that suggest the exact frictional condition. Sticking condition was used in this simulation because it is suitable for forming operations [6]. Shear factor value of 0.4 was applied in the simulation observed from previous study.

3. Results and Discussion

3.1 Analysis of temperature distribution on the workpiece

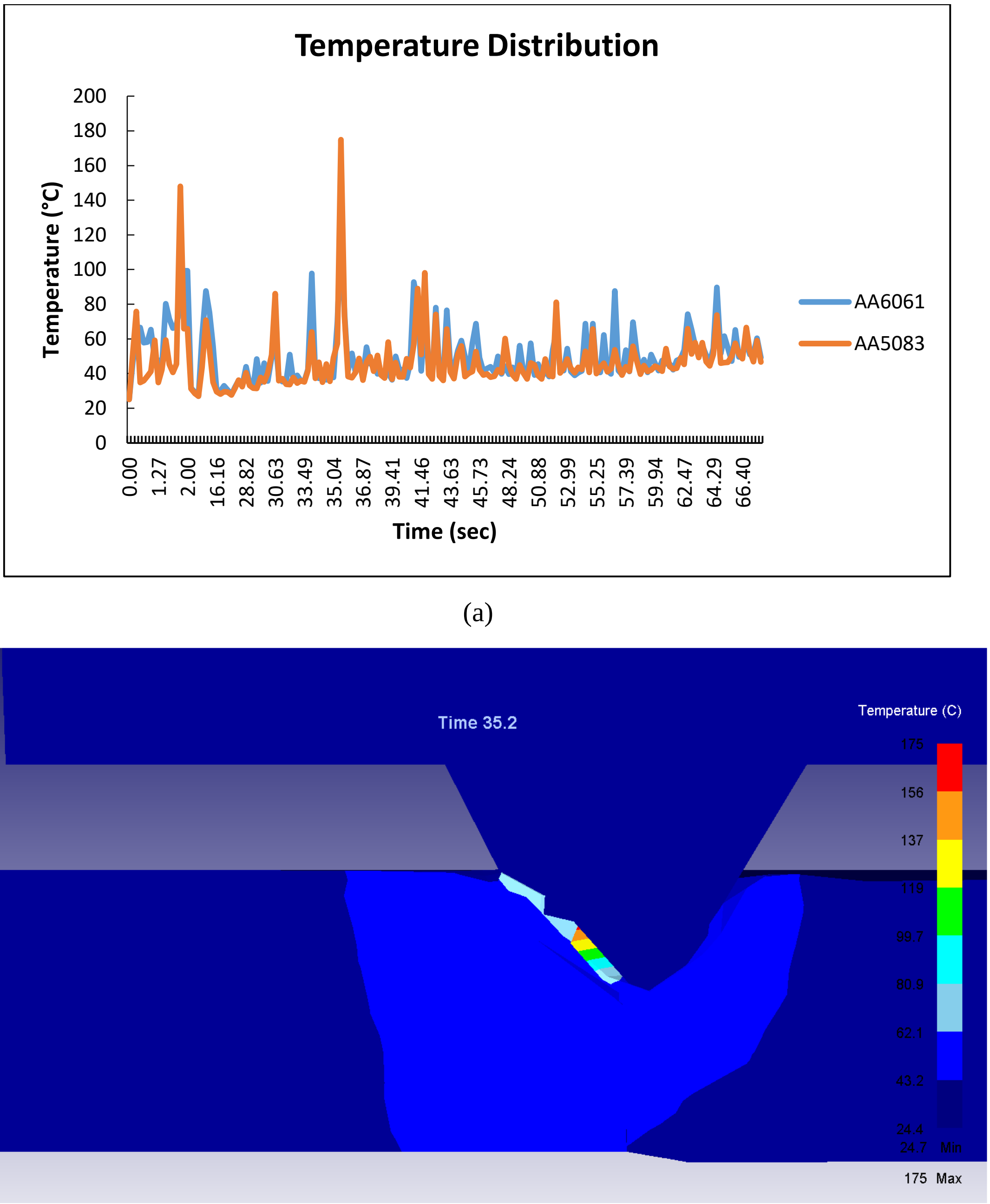
The data from the graph below show uneven of temperature distribution. In the FSW process, a high amount of heat is needed to plasticize the material, which allows for material mixing to create a good weld. Heat is produced in FSW process because of plastic deformation of the material and frictional heat occurred between the tool and the workpiece [7]. The uneven temperature distribution along the transverse direction of welding might be happened due to lost contact between tool and workpieces caused by deficiency boundary condition setup. Contact area between tool and workpiece are important in this FSW process simulation to generate frictional heat. It is required to have sufficient temperature on the interface of tool-workpiece to keep welding materials in plasticized state. Plastic deformation and frictional heat are the major sources of heat generation [5].



(a)

(b)

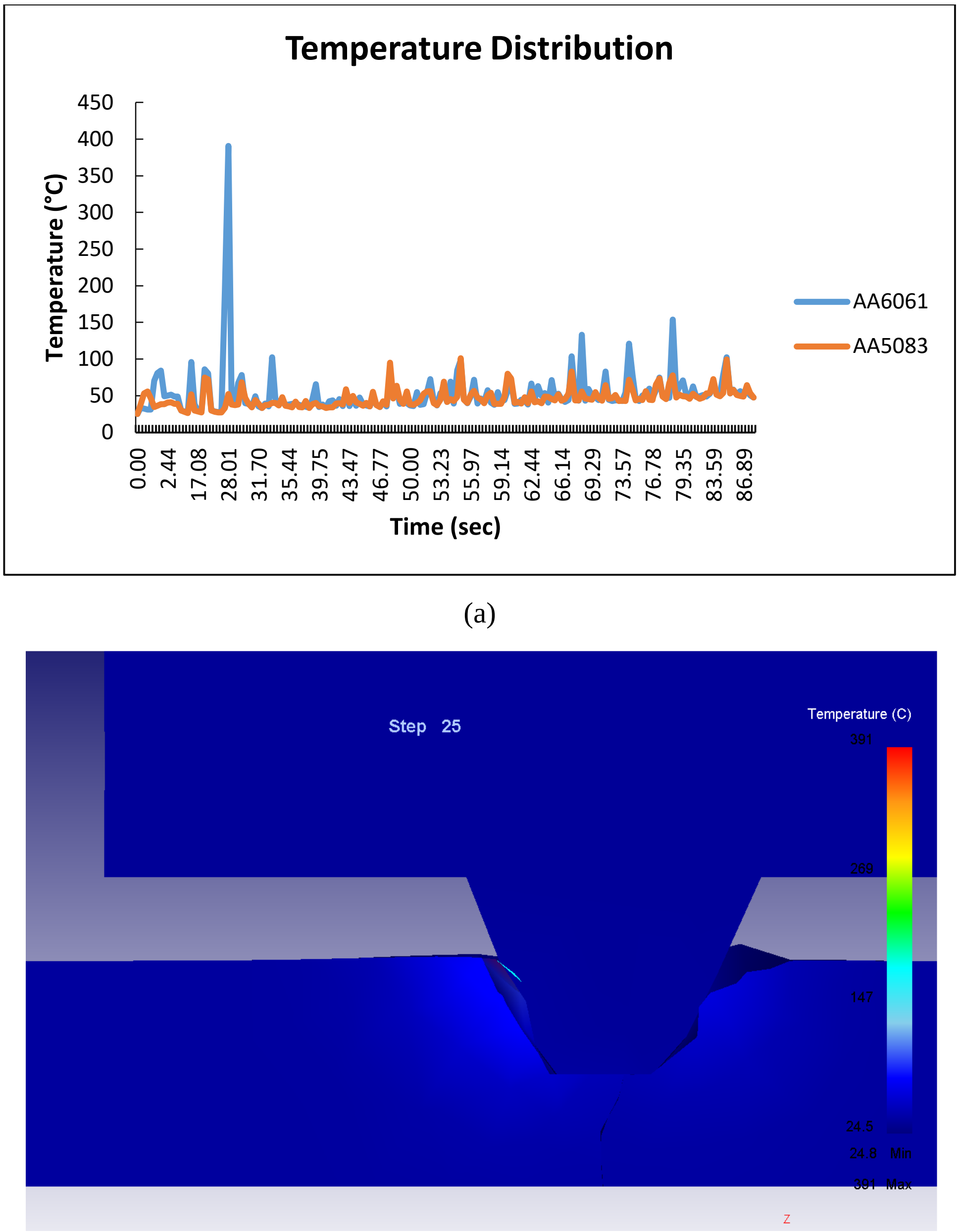
Figure 3: (a) Temperature distribution and (b) temperature profile on workpiece AA6061 and AA5083 at 700 rpm and 80 mm/min



(a)

(b)

Figure Error! No text of specified style in document.**: (a) Temperature distribution and (b) temperature profile on workpiece AA6061 and AA5083 at 1400 rpm and 60 mm/min**



(a)

(b)

Figure 5: (a) Temperature distribution and (b) temperature profile on workpiece AA6061 and AA5083 at 1400 rpm and 40 mm/min

The highest temperature recorded was 223°C happened during plunging stage on workpiece AA6061 and 93°C during welding stage on workpiece AA5083 extracted from simulation FSW at 700 rpm and 80 mm/min. For simulation FSW at 1400 and 60 mm/min, the highest temperature recorded was 120°C happened during welding stage on workpiece AA6061 and 175°C on workpiece AA5083. Lastly, the highest temperature recorded was 391°C happened during dwelling stage on workpiece AA6061 and 101°C during welding stage on workpiece AA5083 extracted from simulation FSW at 1400 rpm and 40 mm/min.

3.2 Discussions

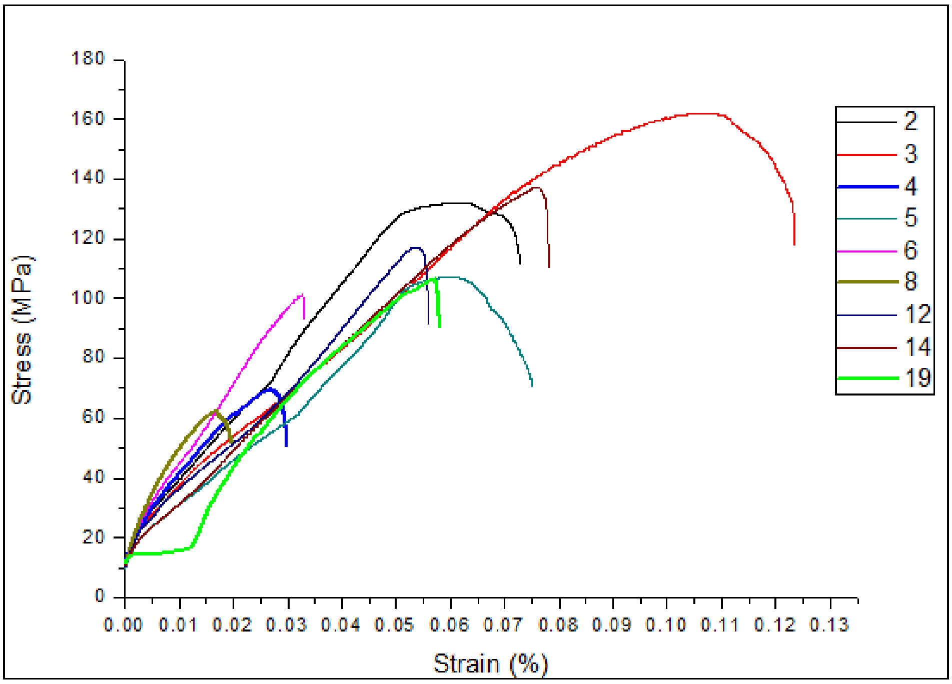


Figure 6: Stress Strain Graph for each Specimen [4]

Figure 6 shows stress and strain results of all 9-specimen fabricated through FSW process. It shows that specimen no. 3 has the highest tensile strength at 161.970 MPa with setting parameter of 700 rpm in rotational speed and feed rate of 80 mm/min. Specimen no.8 has the lowest tensile strength of 62.386 MPa with parameter setting of 1400 rpm for rotational speed and feed rate of 40 mm/min. Moreover, the parameters that used for specimen no. 3 generate an extreme plastic deformation on the specimen which led to better welding and better mechanical properties for weld joint [4].

Due to the uneven data for temperature distribution, the outcome for effective strain and effective stress graph also showed uneven trend line. Results from simulation data were unable to shows similar results as experimental results for strength of welded joint due to uneven line trends in temperature distributions. The outcome from the temperature distributions lead to the formation of groove along the transverse welding direction in the simulation. Furthermore, the FSW process need to generate temperature higher than half temperature of melting point for the materials so that it can achieve recrystallization temperature. Recrystallization phenomenon happens at high strain rates and high temperatures (higher than half of the material's melting temperature) [8].

3.3 Comparison from simulations results

Figure 7 to 9 show the graph of stress against strain for both materials AA6061 and AA5083 at different rotational speed and transverse speed. It is difficult to explain the result, but it might be related to the uneven temperature distribution. Based on the experiment result, the stress increased gradually with strain value. The graphs below show uneven data distributions. The temperature of FSW process at 700 rpm and 80 mm/min should be highest among the other two cases in this study. These results seem to be inconsistent with experimental results. High frictional temperature and plastic deformation are needed to produce high quality of welded joint. A possible explanation for these results may be the missing of another input parameter data from the experiment.

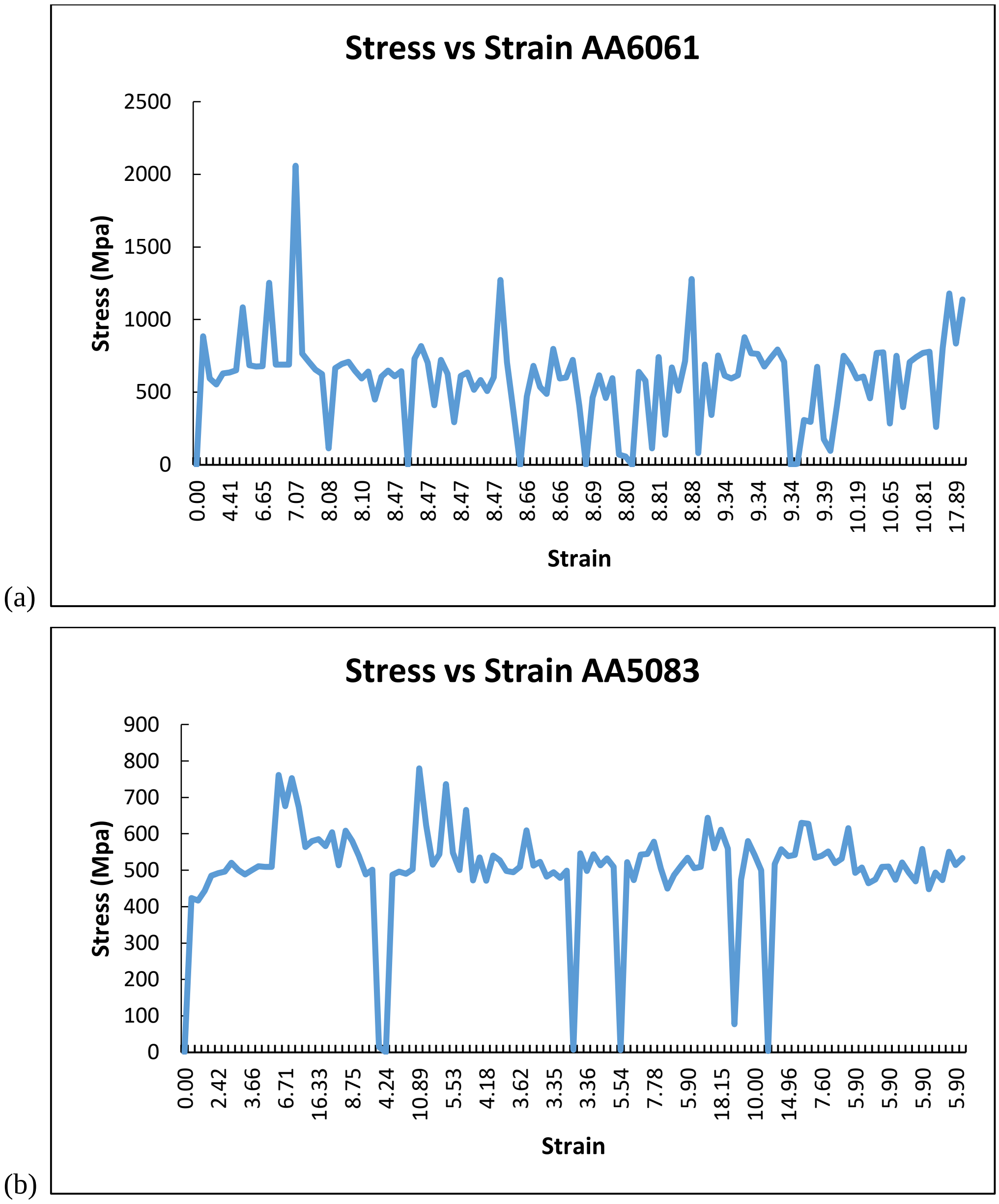


Figure 7: Stress Strain Graph for (a) AA6061 and (b) AA5083 at 700 rpm and 80 mm/min

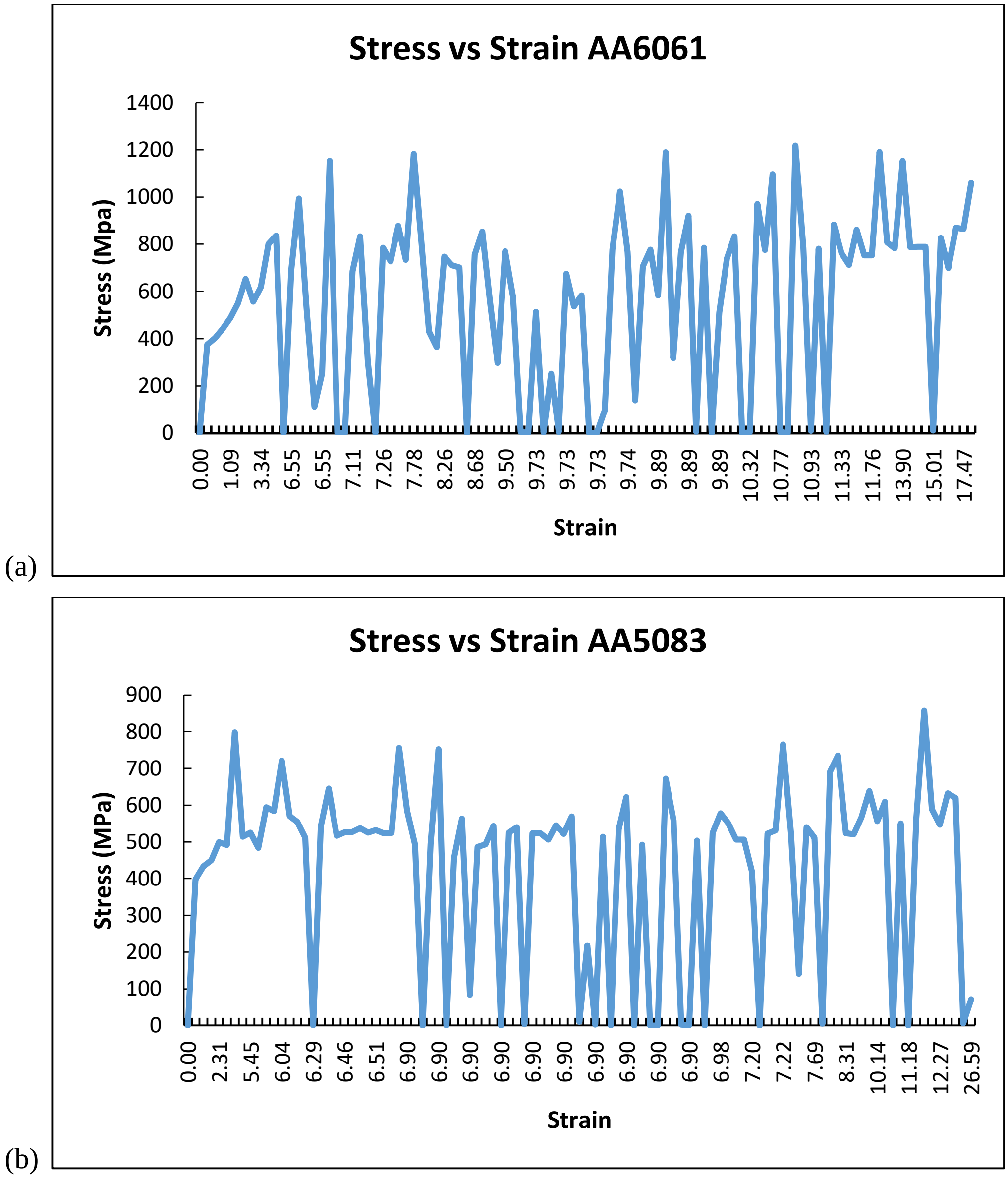


Figure 8: Stress Strain Graph for (a) AA6061 and (b) AA5083 at 1400 rpm and 60 mm/min

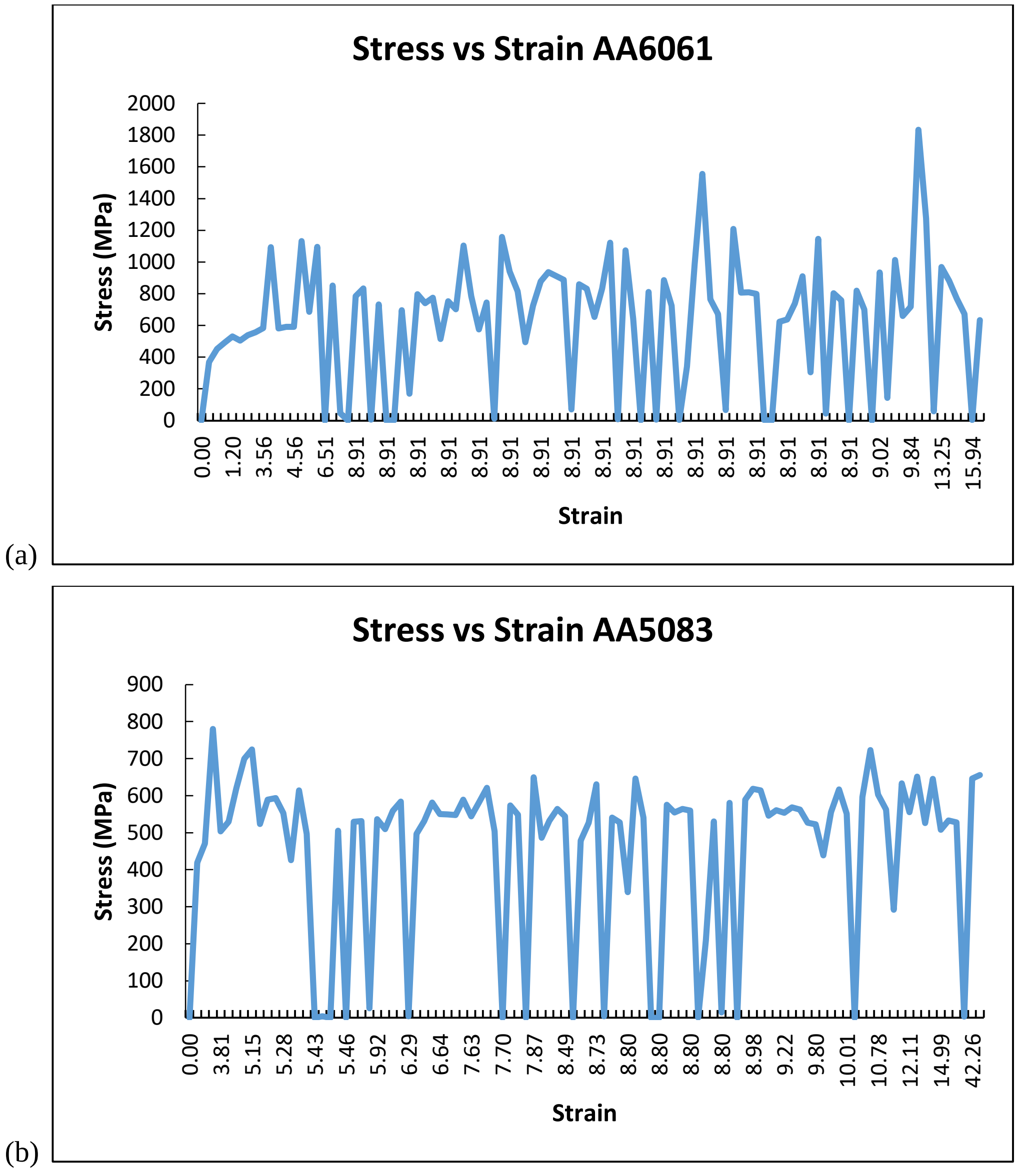


Figure 9: Stress Strain Graph for (a) AA6061 and (b) AA5083 at 1400 rpm and 40 mm/min

4. Conclusion

In conclusion, the FSW process simulation for dissimilar aluminium alloys which is AA6061 and AA5083 was carried out using commercially available FEM software, the DEFORM-3D. The simulations were carried out to analyse the temperature, strain, and stress distribution at tool-material interface during the FSW process which are difficult to measure experimentally. The simulated results from the study are unsatisfactory due to uneven graph data on temperature, strain, and stress distribution. The main conclusion may be stated as follows based on the results obtained:

i. Heat generation are important in FSW process because high material deformation and frictional heat can be achieved by recrystallization temperature.
ii. Important to study simulation setup especially boundary condition before running the simulation.
iii. Strain and stress distribution are influenced by heat generation between tool and workpiece.
iv. Temperature distribution and effective strain are the main aspect in refinement material microstructure in order to produce good weld joint.

To improve the simulations results of FSW process, there are several recommendations can be proposed. The recommendations are as follow:

1. Find out more on simulation setup of FSW process especially for the material, thermal and frictional model.
2. Applying Johnson-Cook constitutive model for prediction to be more accurate in the simulation results.

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