Temperature Measurement in Friction Stir Welding and Thermomechanical Effect Analysis

Pooja Singh, Audhesh Narayan and Y.G. Bala

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Temperature Measurement in Friction Stir Welding and Thermo-mechanical Effect Analysis

Pooja Singh*, Dr.Audhesh Narayan† and Dr.Y.G.Bala°

*†°MNNIT,Allahabad, U.P, 211004.
Presenting authors email: pooja.2020rme07@mnnit.ac.in

Abstract

Friction Stir Welding (FSW) has become widely used in various applications due to its ability to join both similar as well as dissimilar materials using a solid-state welding process. In contrast, arc welding requires the melting of materials, making it difficult to weld low-melting-point materials. The heat generated during welding is a common occurrence, with friction being the primary heat source in FSW. As the stirring zone heats up and softens, plastic deformation occurs between the materials, making this area of the process a crucial focus for further study. In this paper, we aim to investigate the thermo-mechanical effects of temperature rise and predicted the stirring zone's temperature to gain a better understanding of FSW.

1. Introduction

Friction stir welding (FSW) is a crucial technique in the manufacturing industry, where the chemical and physical processes play a significant role in the development of the welding joint quality and performance. To control these parameters, measuring the transient temperature during FSW is of utmost importance. Many studies conducted to analyse temperature field during FSW, where experimental methods are commonly verify numerical simulation results. Measured input heat under different welding parameters for FSW of 5083 aluminium alloy using calorimeter and developed an empirical equation to estimate the welding temperature also embedded thermocouples to measure time dependent temperatures accurately at tool work-piece interface during FSW and proposed a physical tool for obtaining the moving response of the temperature distribution. However, experimental study has low detection efficiency as well as poor results of continuity because of the lack in measurement methods for effective online temperature . This can result in resource wastage and may not be accurate for FSW temperature field [1]. The FSW (Friction Stir Welding) process subjects materials to significant deformation, high temperatures, and strain rates. To accurately model the material behaviour, it is crucial to establish the flow stress, a temperature function, strain and strain rate . For this reason, the work-piece is typically treated as a rigid viscoplastic material that exhibits rate dependence. Elastic deformation behaviour of materials is typically ignored to improve computational part [2]. The interface between aluminium and steel was monitored to record the temperature history during the process. The tool shoulder in contact with the work-piece substrate, most of the friction heat was generated at this point. The pin penetrated the steel substrate to a depth of only 0.2 mm, while the rest remained in the aluminium. To measure the distribution of temperature accurately, K-type thermoplastic were install within the interface of aluminium-steel, at 3 mm distance away from the weld center.[3]. At an increasing tool rotating speed from 400 to 1000 rpm, the maximum welding temperature was observed to rise from 532 K to 675 K . Similar size of the pin used for FSW and measured the temperature of FSW tool during FSW under 50 mm/min,800 rpm, with the help of a blue-tooth wireless temperature monitoring unit. They recorded a pin temperature of ~ 623 K as the welding process achieve the equilibrium stage. This is consistent with the maximum temperature 611K measured in our study with same welding parameter. Similarly, a maximum welding temperature 615 K under 50 mm/min and 800 rpm, using a similar size tool, which also satisfy the maximum temperature measured in our study. Therefore, the temperature reliability history measured in this study is confirmed [4]. The rate of the temperature rise depends on the tool insertion rate. Insertion of the tool until the shoulder get intimate contact with work-piece surface. Once this occurs, the tool shoulder and the pin both contribute to friction heat, and the force decreases gradually due to metallic work-piece reaches maximum temperature for the plastic material flow. This time period is referred as the "dwell time".Longer dwell time shows a higher contribution in frictional heat by the shoulder of the tool and pin surface, then the result summarize the higher temperature recording. The maximum temperature recorded follows the same trend [5].

2. Process Methodology

The welding process begins with the tool - work-piece (AA 2024) at atmospheric temperature. The tool (H13 tool steel) is secured in the shoulder of the machine, while the work-piece is fixed to the attachment on the drilling machine, which moves in a forward and backward direction. Starting point of the process, both the tool, work-piece are cold, and only drilling occurs between them. After a period of dwell time, the tool insertion process commences until the shoulder contacts the work-piece. Initially, the chip of the work-piece material forms similarly to the machining process. However, as time passes, the tool shoulder and pin surface generate heat due to friction, causing the metallic material to reach a critical point of plastic flow. At this stage, less force is required to move the tool. The high value of dwell time contributes to a high level of frictional energy, resulting in a maximum temperature recorded.

3. Study of Thermal history

The friction stir welding process, temperature distribution varies depending on the amount of heat generation by the friction between the tool and work-piece. Frictional energy and plastic deformation are the main sources of heat. The highest temperature is typically obtained at the joint. The joint quality is highly dependent on temperature because the heat dissipated during the friction stir welding determines the further movement of the tool into the work-piece. If the temperature provided is not sufficient for softening the material, the tool may stop or break, and the desired quality of the weld may not be achieved. Proper material flow is critical to maintaining good weld quality and tool life. The temperature study is crucial in the friction stir welding, and the temperature range must be limited. If the temperature is too low, defects may be present in the weld joint. On the other hand, if the temperature is too high, material may stick between the tool- workpiece, leading to a large grain size microstructure. Increasing the dwell time from 10 seconds to 30 seconds can result in an increase in the maximum temperature recorded, as reported by S. Verma et al.

4. Thermal model

The heat transfer equation used for the thermal process for defining the heat generation in welded material for the plastic flow

$$Q_f = 2\pi n F_f \left[\pi(x^2 + y^2) + 2\pi \frac{\sqrt{H^2 + (R_2 - R_3)}}{H} \sqrt{x^2 + y^2} z \right] t \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This equation is used for the three-dimensional heat generation due to given heat flux from the FSW tool [1].

Where n= rotational speed in rpm, F_f= frictional force between tool and work-piece, x= x axis distance, y= y axis distance, z = in z axis distance, H= height of the pin, R_2=top radius of the tool pin, R_3=root radius of the tool pin, t= time.

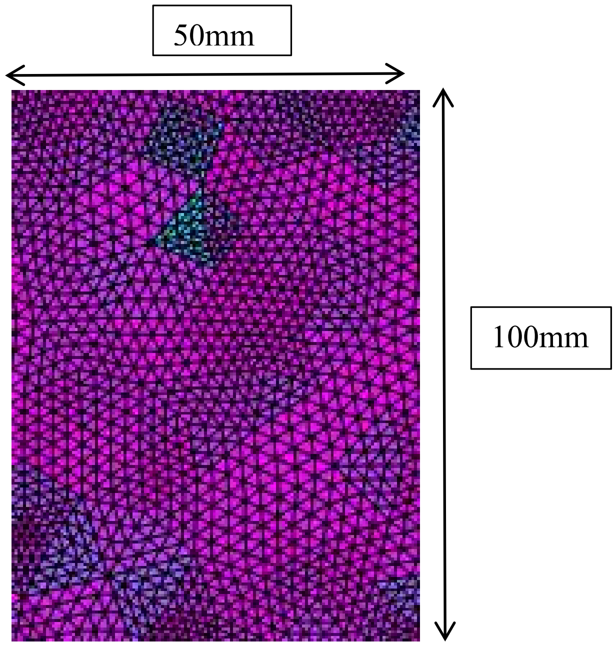


Figure 1. Domain information and the meshing

According to equation (2) we can see that the value of heat generation depends on the time involve in welding and geometry of the tool is also a significance factor.

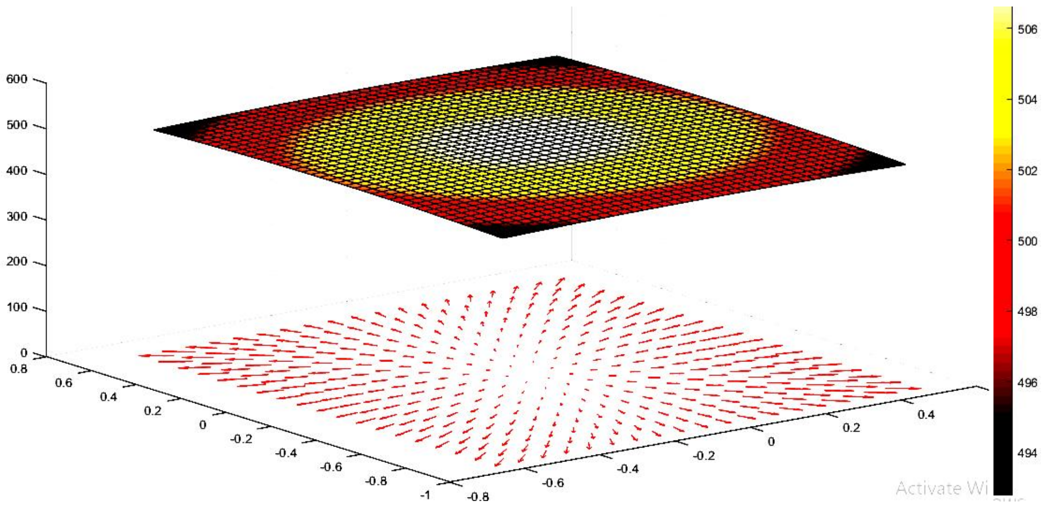


Figure 2. Temperature variation due to heat flux given by tool

The present temperature distribution predicted by the total heat generation in equation number (2). which totally depends on the tool parameters, rotational speed, tool geometry and the yield strength of the contact [7].

$$Q_{Total} = \frac{2}{3}\pi\tau_{contact}\omega\left[(R_{Shoulder})^3 + 3R_{Probe}^2 . H_{probe}\right]........(2)$$

Where $\tau_{contact} = \frac{\sigma_{yield}}{\sqrt{3}}$, ω =rotating velocity of the tool(rpm), $R_{Shoulder}$ =Radius of the shoulder(mm), R_{Probe}=Radius of the pin or probe(mm),H_{Probe}= tool pin height.

5. Thermo-mechanical analysis

The plastic flow of material in the FSW is a dual nature phenomenon.Heat flow and the plastic material flow both contributes in the welding process.
The inter-facial friction behaviour in the FSW process done on AA2024-T4 has remained not clear because the lack of dependent thermo-mechanical and coupled flow analysis. Elucidate the friction contact behaviour, including inter-facial temperature including heat generation due to friction, mass transfer and inter-facial stick-slip state are the main topics to study the flow of material. Our results indicate the temperature at the tool workpiece interface distributed homogeneously, ranging from 380 to 506°C after comparing with the Rahul Jai.[2] the vaue of peak temperature is 512°C. We found that heat generation due to slipping type friction is considerably less than the deformation heating, since inter-facial slip-stick behaviour is present over a wide area of tool-workpiece interface,as the proper slipping occured at the periphery of the shoulder and the middlesurface of the pin.

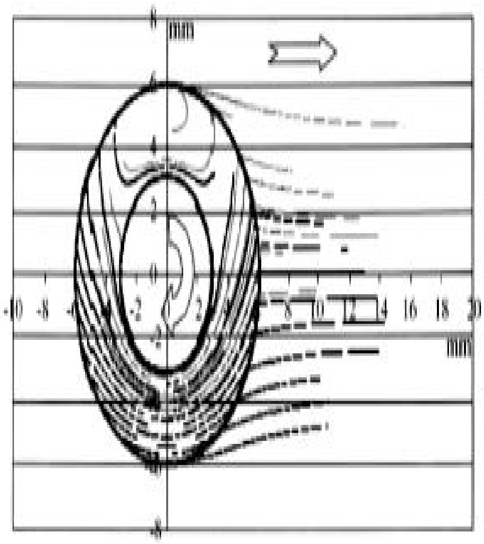


Figure 3. Material flow at shoulder periphery [6]

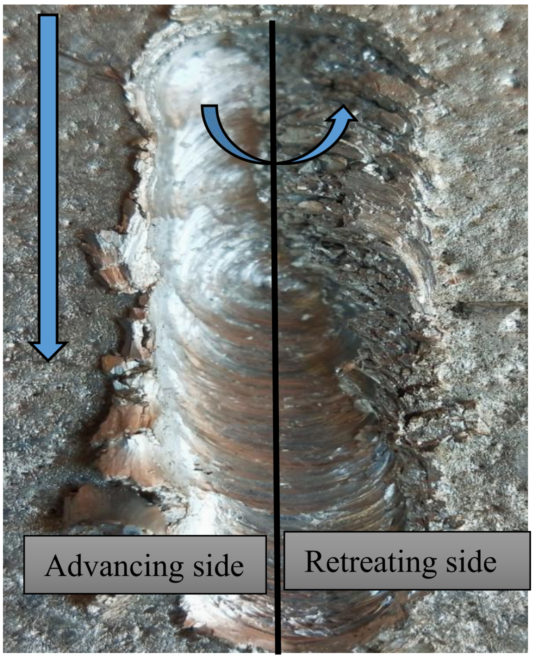
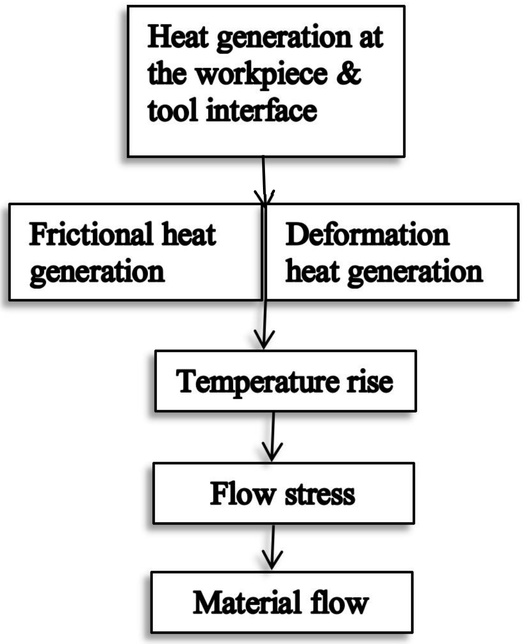


Figure 4. Starting the flow of material

Flow of material from advancing towards retreating side rotates anticlockwise, the deformed material shows the flow of material starts from retreating side. The welding speed is only 600 rpm instead of this low speed, flow of material starts, but the accuracy and defect free quality of the material cannot be achieved this is possible only at the high tool rotating speed.



6. Conclusions

- The amount of heat generation during FSW is depends on the rotational speed of the tool. This means that as the rotating speed increase, so does the temperature at the tool and work-piece interface.
- Temperature control is a complex aspect of friction stir welding process, as it directly affects the welded joint quality and helps to prevent defects. Proper temperature control ensures that the material is heated enough to allow for plastic deformation, but not so much that it becomes overheated and damaged. By maintaining a consistent and controlled temperature throughout the welding process, the risk of defects such as cracks and voids is greatly reduced, resulting in a high-quality, defect-free welded joint.
- In addition of the tool rotating speed, the temperature during FSW is also influenced by the geometry of the tool. when the tool radius increases, the torque required to rotate the tool also increases, which leads to an increment in heat generation between contact of the tool and work-piece. This means that the geometry of the tool play a significant role for determining the temperature distribution during FSW, and must be carefully considered in order to achieve optimal welding conditions and high-quality welded joints.

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7. References

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