Research Article

Analysis Of Heat Generation During Friction Stir Processing of Aluminium Similar Joints

Akshansh Mishra[1], Abhishek Kumar Sharma[2]

Abstract

In this paper, the study of heat generation during friction stir processing of similar joints of AA6061-T6 is carried out. A three dimensional (3D), transient, a non-linear thermal model was developed using ANSYS 16.2 software to simulate the heat generation profile during Friction Stir Processing of similar Aluminium plates. The results showed that the observed temperature rise in the model shows that heat generated during the second and third load steps is due to friction between the tool shoulder and workpiece, as well as plastic deformation of the workpiece material. It was also observed that friction is responsible for generating most of the heat needed, while the contribution of heat due to plastic deformation is less significant. Because the tool-penetration in the workpiece is shallow, the heat generated due to tool pin is ignored and the plastic heat generated is small compared to frictional heat.

Keywords: Friction Stir Processing, Friction, Heat Generation, Plastic Deformation

Introduction

Friction Stir Welding is a substitute of Arc Welding process. The main difference between FSW and other elevated temperature metal working process is that in FSW process, the work pieces to be joined are not at preheated condition. The work pieces are at ambient temperature in the beginning. Friction Stir Welding process can be divided into three phases:

- Plunge and dwell
- Traverse
- Retract

During the plunge phase, both the tool and work piece are at ambient temperature. At the time of insertion of the rotating friction stir tool, chipping is created by the rubbing action between tool and work piece. The rate of temperature rise and extent of plasticity is determined by the rate of tool insertion. During dwell phase, the metals which have higher melting point, in order to reach the desired temperature required for plastic flow, the rotating is maintained at same position for short duration. Once the work piece/tool interface is sufficiently heated up, the tool is traversed along the desired direction to accomplish joining. After the completion of joining process, the tool is retracted from the workpiece.

The primary function of the rotating tool pin is to stir the plasticized metal and move it from front to the back of the pin to have good joint [1]. Elangovan et al. [2] studied the influences of tool pin profile and tool shoulder diameter on

[1]Department of Mechanical Engineering, SRM University,Kattangulathur-603203.
[2]Department of Mechanical Engineering, Indraprastha Engineering College,Ghaziabad-201001.

Correspondence: Akshansh Mishra, Department of Mechanical Engineering, SRM University,Kattangulathur-603203.

E-mail Id: akshansh.frictionwelding@gmail.com

Orcid Id: http://orcid.org/0000-0003-4939-359X

How to cite this article: Mishra A, Sharma AK. Analysis Of Heat Generation During Friction Stir Processing of Aluminium Similar Joints. *J Adv Res Mech Engi Tech* 2017; 4(4): 3-8.

ISSN: 2454-8650

the formation of friction stir processing zone, and reported that the pin profile plays a crucial role in material flow. Accordingly, it regulates the welding speed of the FSW process. The pin is generally cylindrical, frustum tapered, threaded or flat. Pin profiles with flat faces (square or triangular) are sometime associated with eccentricity, which allows incompressible material to pass around the pin profile.Frictional heat is generated between the wear resistant welding tool and the material of the work piece [3]. This heat causes the latter to soften without reaching the melting point and allows the tool to traverse along the weld line [4]. The plasticized material is transferred from the tool leading edge (advancing side) to its trailing edge (retreating side) and is forged by the intimate contact of the tool.

Chen et al. [5] proposed a 3D finite element model to study the thermal impact and evaluation of stresses in weld by considering mechanical effect of tool shoulder. Chao et al. [9] have formulated the heat transfer of the FSW process and observed that about 95% of heat generated from the friction was transferred into the workpiece and only 5% flows into the tool as well as about 80% of plastic deformation work was dissipated as heat. Song and Kovacevic[6] have introduced a moving co-ordinate system in a 3D heat transfer model using finite difference method to reduce the difficulty of modeling the moving tool during FSW. Nandan et al.[7] modeled a 3D visco-plastic flow of metals and the temperature fields in FSW and agreed well with experimental values. Qasim M Doos et al.[8] developed two mathematical models for FSW and observed that transient-thermal model was more accurate than fluid -thermal model. Rajamanickam et al. [9] developed a thermo-mechanical finite element model for FSW of aluminium alloy and observed that thermal modeling is useful to predict temperature near tool shoulder.

Analysis of heat generation due to frictional heating

The friction between two metallic surfaces arises due to two main reasons which are following:

- Interfacial adhesion between asperities on the contacting surfaces
- Microscopic plastic deformation during relative motion of the contacting surfaces

The frictional energy dissipated during microscopic deformations occurring at the surface is entirely converted to heat energy. thus, in reality the frictional force is influenced by the physical and chemical properties of the interacting surfaces and their dependence on the load, relative velocities and temperature there for it is important to note that in FSW these microscopic deformations occur chiefly at the workpirce surface (the tool surface more or less is considered non-deformable although that may not be true for FSW of high temperature materials with refractory metal tools). As a consequence, the heat generated is distributed unequally between the two surfaces (i.e. tool and workpiece) [10].

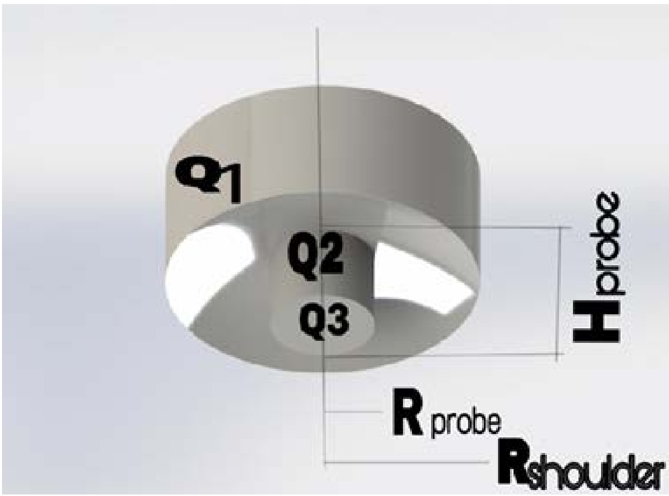

Figure 1.1 Tool Nomenclature used during FSW Process

The schematic of a typical FSW tool, with a cylindrical pin of radius Rpin (i.e. Rprobe in figure), and height Hpin (i.e. Hprobe in figure) and a tool shoulder diameter Hshoulder (i.e. Hprobe in figure), the surface of which is at an angle α with the horizontal is represented in Fig 1.1. The total heat generated at different portions of the tool [11] during welding is sub-divided into the following components depending on the distinct zones of the tool/work-piece interface.

Q_1=Heat Generation at the tool shoulder =

$$2\pi(1+\tan(\alpha))\tau_{shear}(R^3_{shoulder} - R^3_{pin})$$

Q_2 = Heat Generation at the tool pin = 2

$$2\pi\tau_{shear}R^2_{pin}\omega$$

Q_3Heat Generation at the tool pin tip =

$$\frac{2}{3}\pi\tau_{shear}\omega R^3_{pin}$$

In the above heat generation model, both ω and are considered as constant. But, depending on the tool size and the tool rotation conditions these parameters can vary significantly and the heat generation expressions should be modified accordingly.

Although, the heat generation equations described above are independent of traverse speed, the weld heat input decreases and the power consumed increases with traverse speed increase at constant traverse speed to tool rotation rate ratios (i.e. advance per revolution (APR). As the tool traverse speed increases, the heat input to the weld decreases causing less softening of the material around the tool which in turn increases the demand for higher power.

Analysis of Heat generation due to plastic deformation

The localized plastic deformation process occurring in the bulk of the workpiece can also significantly contribute to the heat added to the weld. For example, in a uniaxial tensile test, the total energy (i.e. area under the stress-strain curve) is partially converted to heat, while the remaining is stored in the material microstructure. The amount of this plastic deformation energy which is dissipated as heat can vary between 80 and 100 % of the total input (Hodowany et al. 2000; Kapoor and Nemat-Nasser 1998 [12-13]). Thus, with reference to friction stir welding, the weld power input converted to plastic deformation energy in the bulk can be separated into two parts, (a) fraction stored in the microstructure, and (b) fraction converted to heat. Although, no experi- mental measurements of these individual fractions have been reported for FSW, the results of numerical simulations predict that the extent of heat obtained frombulk plastic deformation can vary between 2 and 20 % according to Russell and Shercliff 1999; Colegrove et al. 2000 [14-15].

Results and Discussions

a) Deformation and stresses: It is important to observe the change in various quantities around the weld line during the FSW process. The following figure shows the deflection of the workpiece due to plunging of the tool in the first load step:

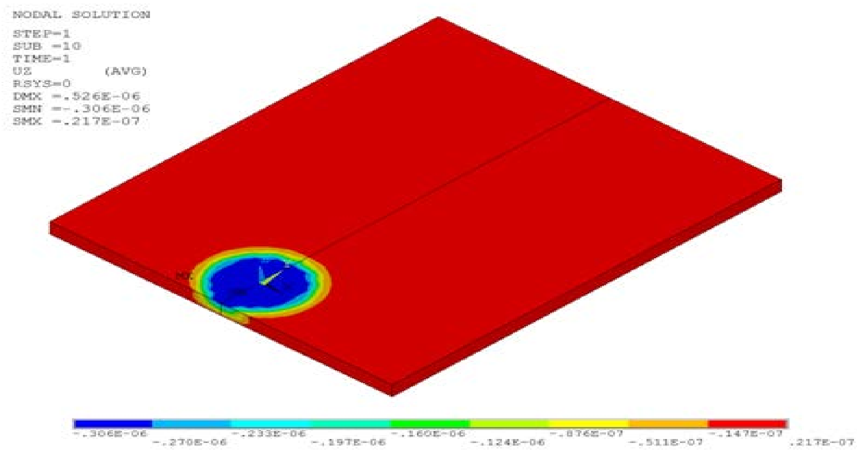

Figure 1.2 Deflection at Workpiece After Load Step 1

The deflection causes high stresses to develop on the workpiece beneath the tool, as shown in the fig 1.3:

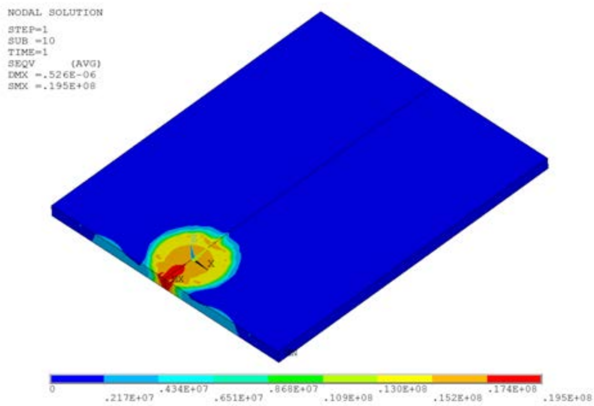

Figure 1.3 von Mises Stress After Load Step 1

As the tool begins to rotate at this location, the frictional stresses develop and increase rapidly. The following two figures i.e. fig 1.4 and fig 1.5 show the increment in contact frictional stresses from load step 1 to load step 2:

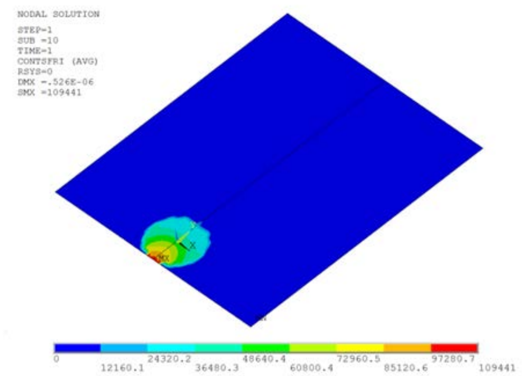

Figure 1.4 Frictional stress after load step 1

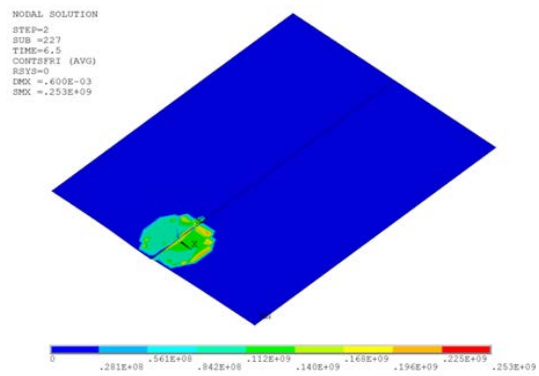

Figure 1.5 Frictional Stress after load step 2

All frictional dissipated energy is converted into heat during load step 2. The heat is generated at the tool-workpiece interface. Most of the heat is transferred to the workpiece (FWGT is specified to 0.95). As a result, the temperature of the workpiece increases rapidly compared to that of the tool.

b) Temperature: The following two figures i.e. Fig 1.6 and Fig 1.7 show the temperature rise due to heat generation in the second and third load steps:

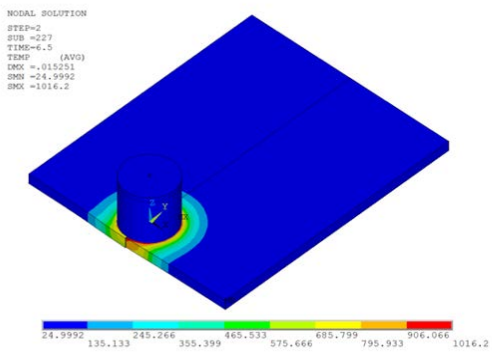

Figure 1.7 Temperature distribution after load step 3

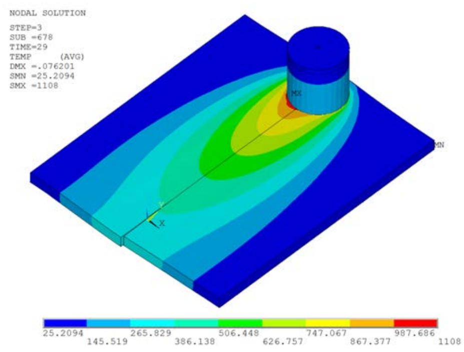

Figure 1.6 Temperature distribution after load step 2

The maximum temperature on the workpiece occurs beneath the tool during the last two load steps. Heat generation is due to the mechanical loads. No external heat sources are used. As the temperature increases, the material softens and the coefficient of friction decreases. A temperature-dependent coefficient of friction (0.4 to 0.2) helps to prevent the maximum temperature from exceeding the material melting point. The observed temperature rise in the model shows that heat generation during the second and third load steps is due to friction between the tool shoulder and workpiece, as well as plastic deformation of the workpiece material.

c) Heat Generation: Friction and plastic deformation generate heat. A calculation of frictional and plastic heat generation is performed. The generation of heat due to friction begins in the second load step. The CONTA174 element's FDDIS (SMISC item) output option is used to calculate frictional heat generation on the workpiece. This option gives the frictional energy dissipation per unit area for an element. After multiplying this value with the corresponding element area, the friction heat-generation rate for an element is calculated. By summing the values from each CONTA174 element of the workpiece, the total frictional heat generation rate is calculated for a given time. It is possible to calculate the total frictional heat-generation rate at each time-step (ETABLE). The following figure shows the plot of total frictional heat generation rate on the workpiece with time:

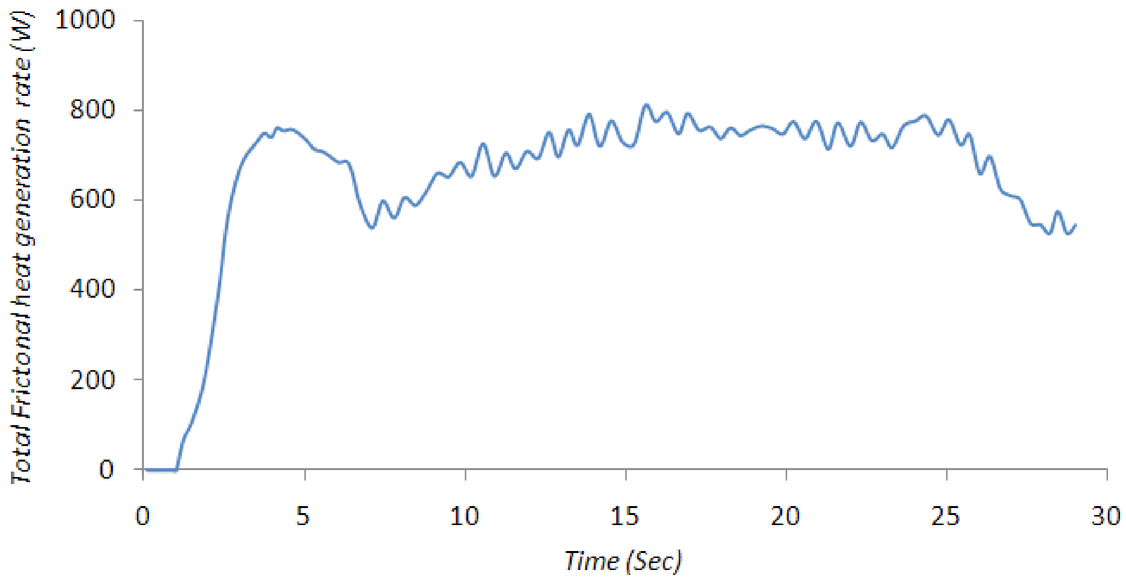

Figure 1.8 Total frictional heat variation with time

The plot indicates that the frictional heat starts from the second load step (after 1 second). The element contact area can be calculated using the CONTA174 element CAREA (NMISC, 58) output option.

A similar calculation is performed to check the heat generation from plastic deformation on the workpiece. The SOLID226 element's output option PHEAT (NMISC, 5) gives the plastic heat generation rate per unit volume. After multiplying this value with the corresponding element volume, the plastic heat generation rate for an element is calculated. By summing the values from each element (SOLID226) of the workpiece, the total plastic heat generation rate is calculated for a particular time. It is possible to calculate the total frictional heat generation rate at each time-step (ETABLE). The following figure shows the plot of the total plastic heat-generation rate with time:

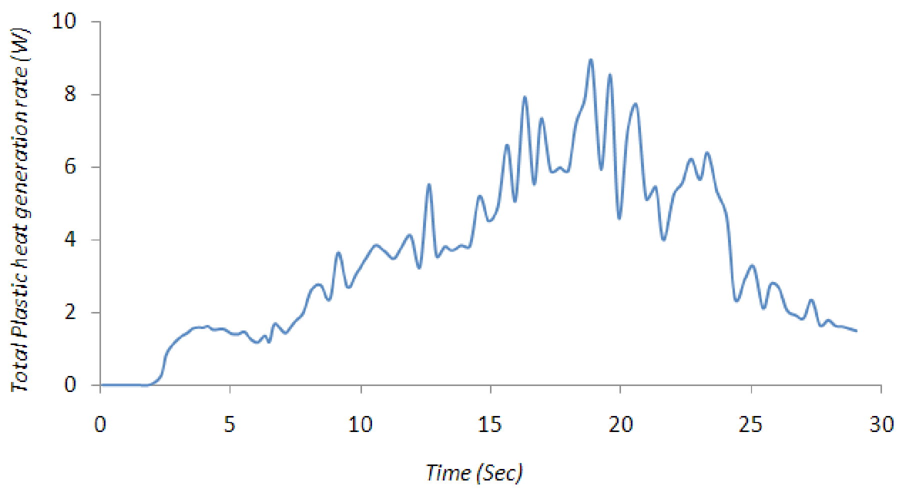

Figure 1.9 Total plastic heat rate variation with time

Fig 1.8 and Fig 1.9 clearly show that friction is responsible for generating most of the heat needed, while the contribution of heat due to plastic deformation is less significant. Because the tool-penetration is shallow and the tool pin is ignored, the plastic heat is small compared to frictional heat.

References

1. *Thomas WM, Dolby RE. Friction stir welding developments. In: Proceedings of 6th international trends in welding research conference. 2002. p. 203–11.*
2. *Elangovan K, Balasubramanian V. Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA6061 aluminum alloy. Mater Des 2008;29:362–73.*
3. *Mishra RS, De PS, Kumar N. Friction stir welding and processing: science and engineering. Springer International; 2014.*

 ISSN: 2454-8650

4. *Su JQ, Nelson TW, Mishra RS, Mahoney M. Microstructural investigation of friction stir welded 7050-T651 aluminium. Acta Mater 2003;51:713–29.*
5. *C.M.Chen and R.Kovacevic , Finite element modeling of friction stir welding – thermal and thermo mechanical analysis, International Journal of machine tools and manufacture 43 (2003) 1319-1326.*
6. *M.Song and R.Kovacevic , Thermal modeling of friction stir welding in a moving co-ordinate system and its validation, International Journal of machine tools and manufacture 43(2003) 605-615.*
7. *R.Nandan, G.G.Roy and T.Debroy , Numerical simulation of 3D heat transfer and plastic flow during friction stir welding, Metallurgical and materials transactions A. volume 37a, (2006) 1247-1259.*
8. *Qasim M.Doos, J.J.Muhsin and D.R.Sarmad , Analysis of friction stir welds. Part I: Transient thermal simulation using moving heat source, First regional conference of Eng. Sci. NUCEJ Spatial issue vol.11, No.3 (2008) 429-437.*
9. *N.Rajamanickam, V.Balusamy,P.R. Thyla and G.Hari Vignesh , Numerical simulation of thermal history and residual stresses in friction stir welding of Al 2014-T6, Journal of scientific and industrial research, Vol.68 (2009) 192-198.*
10. *B. Bhushan, Introduction to Tribology (John Wiley and Sons, New York, NY, 2002).*
11. *11. H. Schmidt, J. Hattel, A local model for the thermomechanical conditions in friction stir welding. Model. Simul. Mater. Sci. Eng. 13, 77–93 (2005).*
12. *J. Hodowany, G. Ravichandran, A.J. Rosakis, P. Rosakis, Partition of plastic work into heat and stored energy in metals. Exp. Mech. 40, 113–123 (2000).*
13. *13. R. Kapoor, S. Nemat-Nasser, Determination of temperature rise during high strain-rate deforma- tion. Mech. Mater. 27, 1–12 (1998).*
14. *M.J. Russell, H.R. Shercliff, Analytical modeling of microstructure development in friction stir welding, in Proc. First Int. Symp. on Friction Stir Welding, June 1999.*
15. *P. Colegrove, M. Painter, D. Graham, T. Miller, 3-Dimensional flow and thermal modeling of the friction stir welding process, in Proceedings of Second International Symposium on Friction Stir Welding, June 2000.*