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Effect Of The Friction Stir Processing Parameters On The Peak Temperature Of Cast A319 Aluminum Alloys

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ABSTRACT

In the present investigation, the peak temperatures during friction stir processing (FSP) of cast A319 Al alloy were measured using thermal imaging technique. The FSP was conducted using different tool rotational speeds, tool traverse speeds and number of passes. The influence of the aforementioned FSP process parameters on the peak temperature were investigated. Moreover, the analysis of variance (ANOVA) statistical approach was used to evaluate the significance of these parameters. The results revealed that increasing the tool rotational speed and/or the number of passes increases the peak temperature. However, increasing the traverse speed reduces the peak temperature. The maximum-recorded peak temperature was about 524 ºC, which is about 85.76% of the melting temperature of A319 alloy.

KEYWORDS: Friction stir processing, A319, Peak Temperature. ANOVA.

1. INTRODUCTION

Friction Stir Processing (FSP) is relatively new solid-state processing method, which is used for the modification of the microstructure of the surfaces of metallic materials [1,2]. FSP was invented based on the principle of the friction stir welding (FSW) technology. During FSP, the friction on the interface between the workpiece and the shoulder of the tool generates heat, which softens the processed material; however, the temperature is kept below the melting temperature of the alloy [3]. During the FSP, the material undergoes severe plastic deformation at elevated temperature, which results in the formation of a structure with dynamically recrystallized fine grains. The knowledge of the heat generation and the temperature history during the FSW/FSP process is very important in understanding the thermo-mechanical interaction occurring during the FSW/FSP process [4]. Several investigators reported the determination of the peak temperature during FSW/FSP processes either experimentally or theoretically using modelling techniques such as finite element method (FEM) [5-9]. For example, *Srinivasan et al.* [5] measured the temperature cycle during the FSP of NiAl bronze plates. Temperature sensing was accomplished using sheathed thermocouples embedded in the tool path within the plates, while simultaneous optical pyrometer measurements of surface temperatures were also determined. The results revealed that the peak temperatures in the stirred zone (SZ) were 990 ºC to 1015 ºC (0.90 to 0.97 T_{Melt}). *Jayesimi et al.* [9] developed new models for the prediction of the peak temperatures in straight and tapered/conical cylindrical profiles FSW tools is presented through an improved analytical heat generation models. The results revealed that that increasing the tool rotational speed at constant weld speed increases the heat input, whereas the heat input decreases with an increase in the weld speed at constant tool rotational speed.

The aim of the present investigation is to study the influences of the FSP process parameters e.g. the tool rotational speed, traverse speed and the number of processing passes on peak temperature of A319 cast Al alloy. The measurements of the peak temperatures were carried out using thermal image camera.

2. EXPERIMENTAL PROCEDURES

The base alloy used in the present investigation is the A319 (Al-Si-Cu) cast Al alloy. The chemical composition of the as-received A319 alloy is listed in Table 1. Ingots from the as-received cast A319 Al alloy were machined into thick rectangular plates with dimensions of 25 mm (width) × 100 mm (length) × 12 mm (thickness).

Table 1. The chemical composition of the A319 cast Al alloy.

Alloy	Chemical compositions (wt%)								
	Si	Fe	Cu	Mg	Mn	Ni	Zn	Ti	Al
A319	6.32	0.31	3.20	0.001	0.002	0.002	0.011	0.006	Bal.

The FSP was performed using FSP tool with a cylindrical pin profile. The dimensions of the pin and the shoulder of the tool is illustrated in Fig. 1. The tool is made from H13 tool steel. A conventional milling machine was used to perform the FSP process as illustrated schematically in Fig. 2. The FSP were conducted using at three different tool rotation speeds (TRS), typically, 1000, 1400 and 1800 rpm, and three different traverse speeds (TS), typically, 40, 60 and 80 mm/min, as well as up to three FSP passes. In each pass, the tool is travelling along the same line as the previous one but in the opposite direction. This means that the advancing side (AS) of the pass became the retreating side (RS) in the later pass. During the FSP of the A319 alloy, the tilt angle was kept constant at 2^{o}.

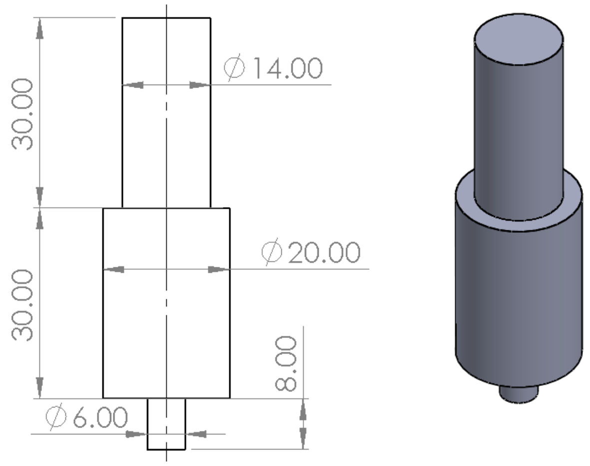

Figure 1. A schematic illustration of the FSP tool (Dimensions are in mm).

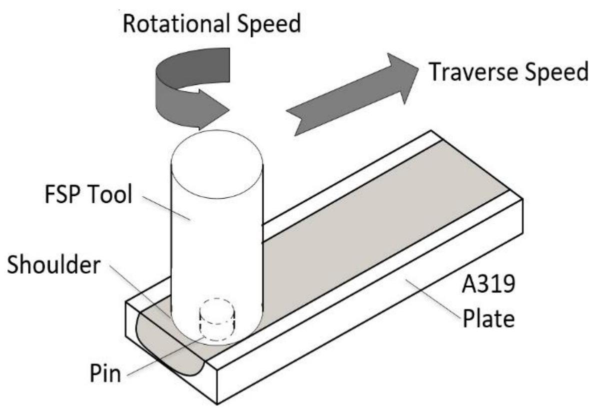

Figure 2. A schematic illustration of the FSP of A319 Al alloy.

The peak temperature on the surface of A319 cast Al plates during FSSW was measured using Fluke Ti32 thermal imaging camera. The thermal camera has a temperature measurement range varies from -20 ^{o}C to 650 ^{o}C. Thermal images obtained from Ti32 thermal imager were analyzed using SmartView imaging analysis and reporting software. Several recordings of images during FSP process were made at different tool rotational and traverse speeds as well as number of passes. In order to eliminate the reflected temperature from the field of view, objects such as anvil were coated by a commercial grade foot-powder. The value of emissivity in the thermal camera was set to 0.25. Such a value was determined based on preliminary experiments. The sample view of a recorded thermographic obtained from the thermal camera during FSP process is shown in the Fig. 3.

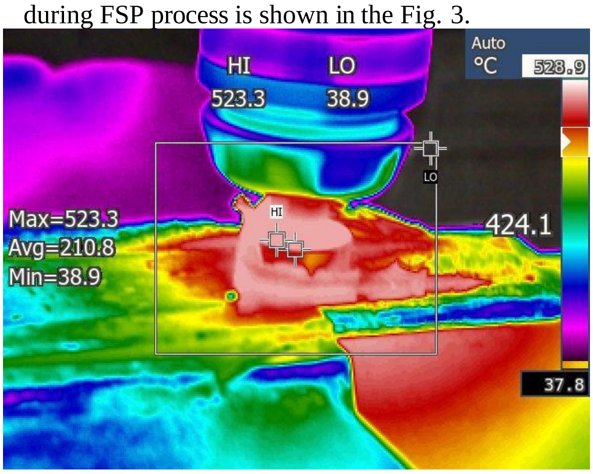

Figure 3. Thermographic image showing the measurement of the peak temperature during FSP using Fluke Ti32 thermal image camera.

3. RESULTS AND DISCUSSION

Figure 4 shows the variation of the peak temperature with the tool rotational speed (TRS) at different traverse speeds (TS) and number of passes (NP). The results revealed that increasing the tool rotational speed and/or the number of passes increases the peak temperature. However, increasing the traverse speed reduces the peak temperature. The maximum peak temperature was about 524 ^{o}C. It recorded for samples FS processed at 1800 rpm, 40 mm/min and 3-passes. While the minimum peak temperature was about 314 ^{o}C. It was recorded for samples FS processed at 1000 rpm, 10 mm/min and single pass. This means that the maximumrecorded peak temperature (i.e. 524 ^{o}C) represents about 85.76% T_m. The melting temperature (T_m) of the present alloywas about 611 ^{o}C [10]. Heating during FSP/FSW is due to a combination of adiabatic deformation in a volume of material surrounding the pin and friction at the interface between workpiece and the tool [5].

The results obtained in the present work are in agreement with several investigators [5-9]. *Mustapha et al.* [6] reported that the peak temperature of the FSW increases by increasing the welding rotational speed for the same tool profile and welding speed. While the peak temperatures were never reach the fusion temperature of the material.

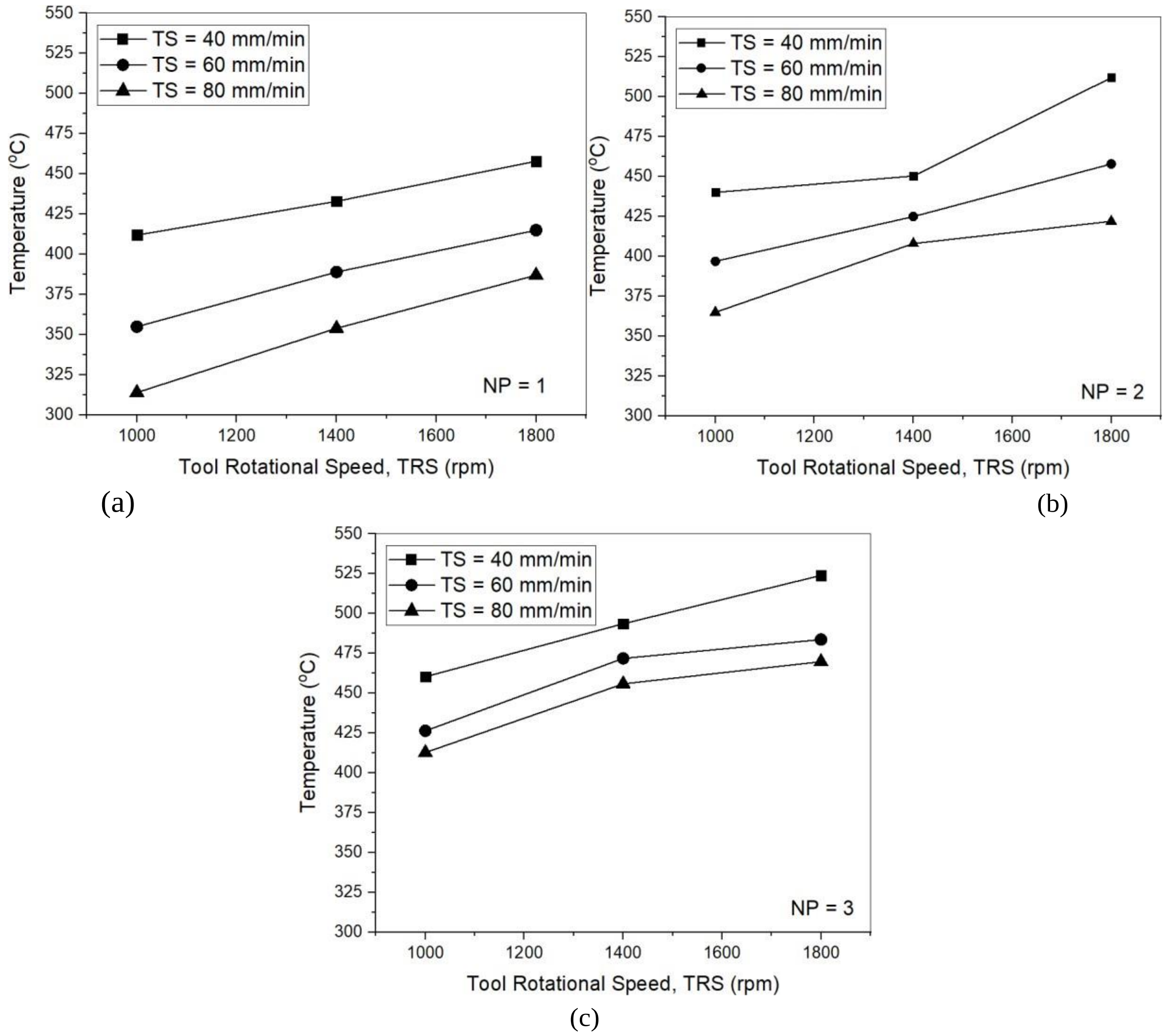

Figure 4. Variation of the peak temperature during FSP of A319 cast Al alloys with the tool rotational speed (TRS) at different traverse speed (TS) and (a) single pass NP=1, (b) double passes NP=2 and (c) three passes NP=3.

Yuh et al. [4] reported that the maximum temperature created by FSW process ranges from 80% to 90% of the melting temperature of the welding material. *Jayesimi et al.* [9] showed that increasing the tool rotational speed at constant weld speed increases the heat input, whereas the heat input decreases with an increase in the weld speed at constant tool rotational speed. *Mayur* and *Mastud* [8] showed that an increase in the rotational speed and coefficient of friction causes increase in the peak temperature in workpeice. The peak temperature reached 80-90% of T_m of base metal in FSW. Variations in process parameters by keeping the geometry same have major effects on temperature profile during FSW. From the temperature distribution results that peak temperature increases by increasing the coefficient of friction, vertical force and tool rotation.

Table 2 lists the ANOVA results for peak temperature recorded during FSP of A319 cast Al alloy. Table 3 shows the response table for means of the peak temperature. Figure 5 shows the interaction plot for the peak temperature. The results revealed that the tool rotational speed (TRS), tool traverse speed (TS) and the number of passes (NP) have significant influence on the peak temperature during FSP of cast Al alloys. Since the probability values (P-values) in Table 2 are equals to 0.000. The P-values of the FSP process parameters (i.e. TRS, TS and NP) must be less than 0.005 to indicate the significance of the parameter. It is clear from Table 3 that the number of processing passes has the most significant physical and statistical influence on the peak temperature (rank #1), followed by the tool traverse speed (rank #2) and then the tool rotational speed (rank #3). Figure 5 shows that there is a slight interaction between the investigated FSP parameters since the lines are nearly parallel to each other.

Table 2. ANOVA for peak temperature, using adjusted SS for tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	16726	16726	8363	74.96	0.000
TS	2	19844	19844	9922	88.93	0.000
NP	2	25864	25864	12932	115.91	0.000
Error	20	2231	2231	112		
Total	26	64666				

S = 10.5625 R-Sq = 96.55% R-Sq(adj) = 95.51%

Table 3. Response table for means of peak temperature.

Level	TRS	TS	NP
1	398.0	464.7	390.8
2	431.1	424.6	430.7
3	458.9	398.8	466.6
Delta	60.9	65.9	75.8
Rank	3	2	1

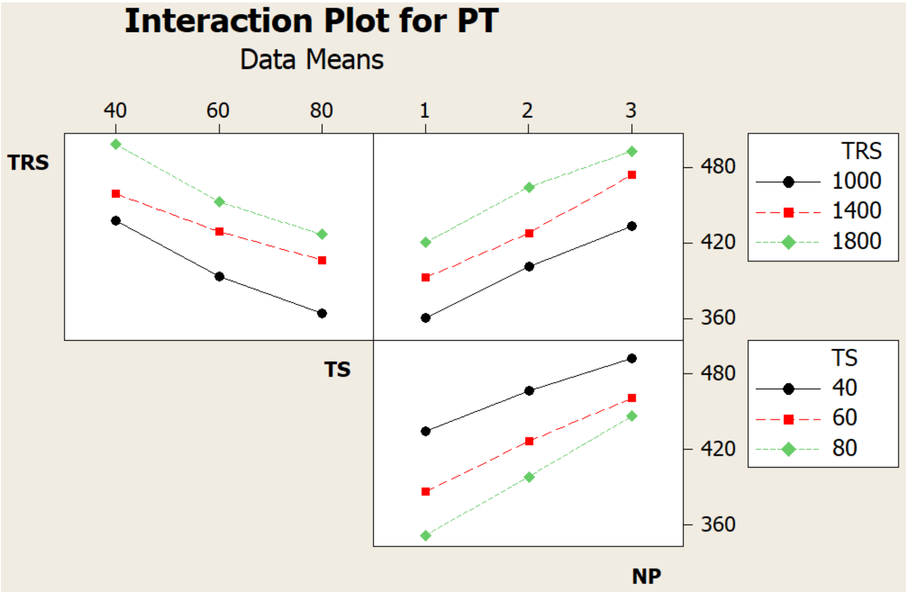

Figure 5. Interaction plot for peak temperature.

4. CONCLUSIONS

Increasing the tool rotational speed and/or the number of passes increases the peak temperature. However, increasing the traverse speed reduces the peak temperature. The maximum peak temperature was about 524 ºC for samples FS processed at 1800 rpm, 40 mm/min and 3-passes. While the minimum peak temperature was about 314 ºC for samples FS processed at 1000 rpm, 10 mm/min and single pass. The maximum- recorded peak temperature represents about 85.76% of the melting temperature of A319 alloy. The number of processing passes has the most significant physical and statistical influence on the peak temperature, followed by the tool traverse speed and then the tool rotational speed.

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