© 2016 IJSRSET | Volume 2 | Issue 2 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Effects of Process Parameters of Friction Stir Processing on Tensile Strength of AA6063 Aluminum Alloy

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ABSTRACT

In this investigation, the effect of friction stir processing (FSP) parameters such as rotational speed, traverse speed and plunge depth on the tensile strength of AA6063 aluminum alloy was studied. The experiments were carried out as per response surface methodology parametric design concepts to study the influence of various combinations of process parameters. Statistical optimization technique, ANOVA was used to determine the optimum levels and to find the significance of each process parameter. The results indicate that rotational speed (RS), and traverse speed (TS) are the most significant factors, followed by plunge depth (PD) in deciding the tensile strength of friction stir processed aluminum alloy. In addition, mathematical models were developed to establish relationship between different process variables and tensile strength.

Keywords: AA6063 aluminum alloy, friction stir processing, response surface methodology, tensile strength.

I. INTRODUCTION

Finding a material with specific properties is one of the most important issues in many industrial applications, especially in the aerospace and transportation industries. So there is a need of designing material with the desired properties. However, there are many limitations in terms of cost and time of production with conventional processing techniques. High strength accompanied by high ductility is possible with materials having fine and homogenous grain structures. There are different processing techniques that would produce a material with small grain size that satisfies the requirements of strength and ductility. New processing techniques like Friction Stir Processing (FSP), Equal Channel Angular Extrusion (ECAE), are being developed for this purpose in addition to the improvements in conventional processing techniques like the Rockwell process, and the powder metallurgy technique.

Friction stir processing (FSP) has recently become an effective microstructural modifications technique. Reported results showed that for different alloys, FSP produces very fine equiaxed and homogeneous grain structure. FSP is considered to be a new processing technique and more experimental and analytical investigations are needed to advance the industrial utilization of FSP. Most of the work that has been done in the friction stir processing field is experimental and limited modeling activities have been conducted.

Mishra et.al (1999) investigated the FSP of a commercial 7075 Al alloy that resulted in significant enhancement of superplastic properties. Kwon et.al (2003) studied the FS processed Al 1050 alloy. The hardness and tensile strength of the FS processed 1050 aluminium alloy were observed to increase significantly with decreased tool rotation speed Sharma et al (2004) have reported the fatigue behavior of friction stir processed A356 alloy. They have reported a reduction in silicon particle size and reduced porosity volume fraction in FSP A356 alloy. An increase in the fatigue strength threshold stress by >80% over the parent material after friction stir processing was reported. Karthikeyan et al (2009) investigated the effects of Friction stir processing on Cast 2285 alloy and concluded that due to FSP the mechanical properties and microstructure are improved. 30% improvement in yield and tensile strengths were recorded and ductility increased around 4 times. He concluded that this improvement in mechanical properties was due to reduced porosity and grain size. Tsai and Kao (2012) reported that the improvement of mechanical properties of a cast Al-Si base alloy can be achieved by friction stir processing. They reported that the tensile properties of cast AC8A alloy could be improved after FSP. Magdy and Ehab (2012) have studied the influence of multi-pass friction stir processing on the microstructural and mechanical properties of aluminum alloy 6082. They reported that the effect of increasing the number of passes led to an increase in the SZ-grain size, more dissolution and reprecipitation with simultaneous intense fragmentation of second phase particles all of which are attributed to accumulated thermal cycles. Darras et al (2015) studied the effect of various friction stir processing parameters on the thermal histories and properties of commercial AZ31B-H24 magnesium alloy sheet. They refinement and homogenization of microstructure is more an observation in a single pass. Fine grain size can be obtained in a single pass friction stir processing through severe plastic deformation and control of heat input during processing.

Fadhel A. et.al (2015) performed friction stir process (FSP) to enhance surface properties of AA2024-T3 alloy. The effect of friction stir shoulder rotation in addition to its pressing effect on surface topography and mechanical properties was studied. Samples were FS processed with a flat pinless cylindrical shoulder of 10mm diameter with a constant rotational and travel speeds 945 rpm and 85mm/min respectively. The maximum hardness increment is about 40-45% and the maximum value obtained at the surface is 190Hv compared to 130Hv before processing. A little bit increase was recorded in yield and tensile strengths by an amount of 15% and 9% respectively after FSP.

Friction Stir processing (FSP) (figure 1.) was developed as a generic tool for microstructural modification based on the basic principles of Friction Stir welding (FSW).
To carry out friction stir processing a location within a plate or sheet is selected and a specially designed rotating tool is plunged into the selected area. The tool has a small diameter pin with a concentric larger diameter shoulder. When descending to the part, the rotating pin contacts the surface and rapidly friction heats and softens a small column of metal. The tool shoulder and length of entry probe control the penetration depth. When the shoulder contacts the metal surface, its rotation creates additional frictional heat and plasticizes a larger cylindrical metal column around the inserted pin. The shoulder provides a forging force that contains the upward metal flow caused by the tool pin. During FSP, the area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the entire selected area is processed to a fine grain size. The rotating tool provides a continual hot working action, Plasticizing metal with a narrow zone, while transporting metal from the leading face of the pin to its trailing edge. The processed zone cools, without solidification, as there is no liquid, forming a defect- free recrystallized, fine grain microstructure.

II. METHODS AND MATERIAL

The experiments were carried out on CNC Milling machine installed at CTR Ludhiana, Punjab India. The milling machine used has a capability of processing plate thickness for 0.5 mm to 10 mm with ease. The specially designed fixture was clamped on bed of vertical milling machine. The tool was mounted on the vertical spindle. The required size plates of 150 mm wide and 100 mm long were taken from the sheet of AA6063. With the help of trial experiments four parameters like tool rotational speed, processing speed, and plunge depth were considered for friction stir processing of aluminum alloy. After selection of the range of the parameters design matrix was developed. Experimentations were performed as per the design matrix. Single pass procedure was followed to process the material. Friction stir processed material was prepared on plates having dimensions (150 x 100x 5) mm using single pass. The plate to be processed was securely clamped in the fixture so that the plate stay in place and do not fly away due to the processing forces. The rotational motion of the spindle was started and the tool was than kept in contact with the surface of the plate and the pin was penetrated to a predetermined depth as per design matrix in the surfaces of the plate to be processed. The tool was given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced and afterwards the tool was given forward motion which processed the material. The tool was withdrawn after the processing was completed, the process leaves a hole at the end of the joint. Visual inspection was performed on all samples in order to verify the presence of possible macroscopic external defects such as surface irregularities, excessive flash and lack of penetration or surface open tunnel, voids etc. All plates were processed as per the design matrix and specimens were prepared for tensile testing. Experimental results for tensile strength are given in Table 1.

Table 1: Experimental results for tensile strength

Run	RPM	PS	PD	Tensile strength
1	1200	120	4.82	214
2	900	90	4.78	223
3	1200	120	4.74	214
4	900	30	4.78	216
5	900	90	4.78	223
6	900	90	4.78	222
7	900	150	4.78	224
8	600	120	4.74	228
9	900	90	4.78	223
10	900	90	4.86	209
11	600	60	4.82	210
12	600	120	4.82	220
13	900	90	4.78	222
14	1200	60	4.82	220
15	1500	90	4.78	210
16	900	90	4.7	227
17	900	90	4.78	224
18	1200	60	4.74	212
19	300	90	4.78	226
20	600	60	4.74	217

III. RESULTS AND DISCUSSION

The data generated from the experimentation was used to develop the mathematical models by regression analysis to estimate linear, quadratic and two way interaction effects of the input processing parameters on the FSPed material. Following mathematical models was developed for tensile strength.

Tensile Strength=+222-2.9A+2.06B-2.68C-3.12AB + 2.87AC

A. Direct effect of tool rotational speed on tensile strength

As evaluated from the tensile test, the tensile strength of the joint increases as the tool rotational speed increases up-to certain limit but it shows the decreasing trend as the tool rotational speed increases beyond that certain limit as shown in Figure 2. A decrease in tool rotation speed reduces the temperature distribution in the processing zone and produces low heat input. This lower heat input condition resulted in lack of stirring and yielded lower It is clear that in FSP as the rotational speed increases the heat input also increases. More heat input destroys the regular flow Figure 2: Direct effect of tool rotational speed on tensile strength joint strength. Behaviour led to higher heat input resulting in slow cooling rate. The slow cooling rate provides ample time for the grains to grow in the stir zone and HAZ, which led in decrease in tensile strength.

B. Direct effect of processing speed on tensile strength

At lower processing speed (60 mm/min), tensile strength of the FSPed material is lower. When the processing speed is increased from 30 mm/min, correspondingly the tensile strength also increased (Figure3).

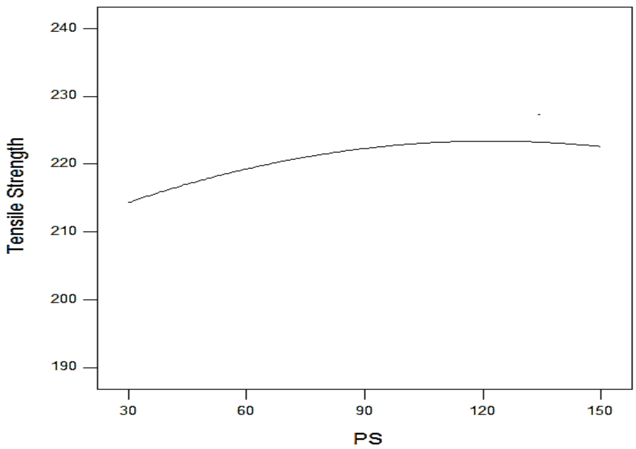

Figure 3: Direct effect of processing speed on tensile strength

When the processing speed was lower, heat input in the weld zone was high. Due to high heat input coarse grains were developed in the stir zone. With the enhancement of processing speed, interaction between tool and work piece was improved. Due to improved interaction of tool and work-piece frictional heat generation per unit length of the material gets reduced, which resulted in faster cooling rate. The faster cooling rate provides short time for the grains to grow in the stir zone and HAZ, which led in increase in tensile strength.

C. Direct effect of plunge depth on tensile strength

From figure 4, it is found that when plunging depth increases tensile strength decreases. At 4.7 mm plunging depth, the tool shoulder generates less amount of heat compared all other plunging depths, which leads to less heat input.

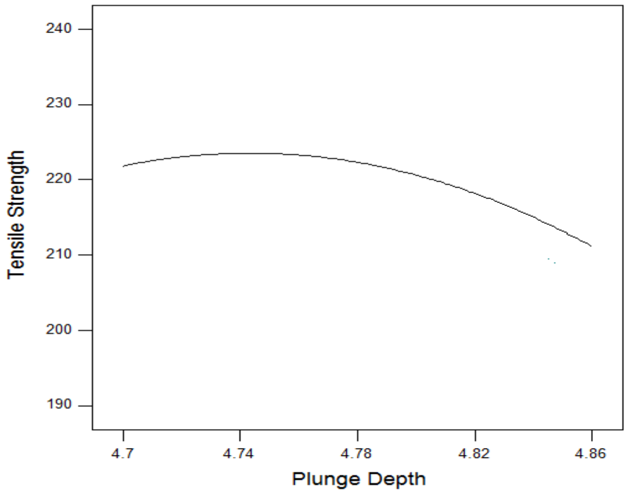

Figure 4: Direct effect of plunge depth on tensile strength

When plunging depth increases, the shoulder contact increases with base plate. This excessive rubbing results in high friction heat generation. Higher heat input resulting in slow cooling rate. The slow cooling rate provides ample time for the grains to grow in the stir zone and HAZ, which led in decrease in tensile strength.

D. Interaction effects of tool rotational speed and processing speed on tensile strength

The interaction effect of tool rotational speed and processing speed (NS) on tensile strength is presented in figure 5. As shown in this figure, at the lower tool rotational speed of 300 rpm and 600 rpm tensile strength of the joint was increased by change in the levels of processing speed but as the tool rotational speed was increased to higher level (900 rpm), the tensile strength started decreasing at all levels of processing speed. These effects are explained with the help of response surface graph as shown in the fig. 5.4. Thus it is evident from the discussion above that the interaction of tool rotational speed and processing speed plays a predominant role in friction stir processing.

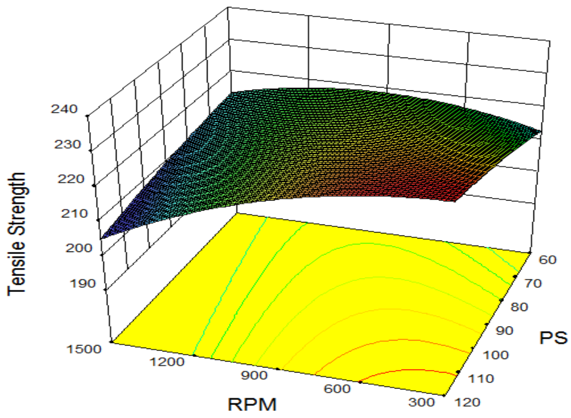

Figure 5: Interaction effect of tool rotational speed and processing speed on tensile strength

E. Interaction effect of tool rotational speed and plunge depth on tensile strength

The interaction effect of tool rotational speed and plunge depth (PD) on tensile strength is presented in figure 6.

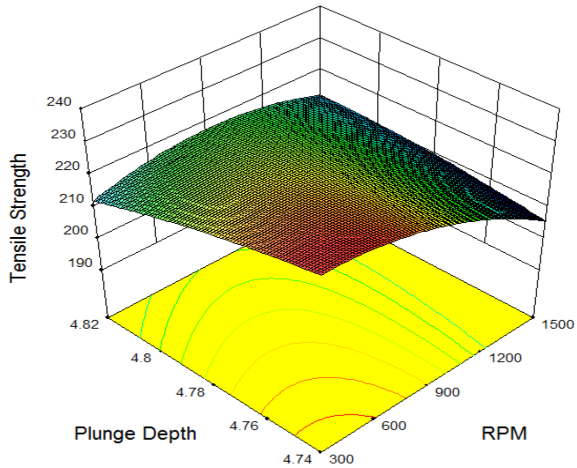

Figure 6: Interaction effect of tool rotational speed and plunge depth on tensile strength

As shown in this figure, at the lower tool rotational speed of 300 rpm and 600 rpm tensile strength of the joint was decreased by increase in the levels of plunge depth but as the tool rotational speed was increased to higher level (1200 rpm & 1500), the tensile strength started increasing by increase in the levels of plunge depth. These effects are explained with the help of response surface graph as shown in the figure 6. Thus it is evident from the discussion above that the interaction of tool rotational speed and plunge depth plays a predominant role in friction stir processing.

IV. CONCLUSION

From the results derived from these experimentations following conclusions have been drawn.

- A five level three factor design matrix based on the central composite rotatable design technique could be effectively used for the development of the mathematical models.
- Response surface design was found to be an effective technique for developing mathematical models to accurately predict the main, quadratic and two-way interaction effects of various input parameters on different responses.
- Tensile strength of the FSPed material decrease with increase in tool rotational speed.
- Tensile strength of FSPed material joints increase with increase in processing speed.
- Tensile strength of FSPed material joints decrease with increase in plunge depth.

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