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Analysis on Tensile Properties of Friction Stir Welded Dissimilar Aluminum Alloys

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***Abstract*: The new joining process called Friction stir welding (FSW) is a relatively used in aerospace industry. This welding process that can produce high quality joints of aluminum alloys because it does not need consumable filler materials and can eliminate some welding defects such as crack and porosity. This present study focus on to study the effects of process parameters viz tool rotation speed, traverse speed, on the tensile properties of friction stir welded dissimilar aluminum alloys AA2024 and AA7075. This friction stir welding process can be used to join these dissimilar alloys without difficulty. These alloys are the most common materials in the aerospace and marine industries because of the high strength to weight ratio and excellent corrosion resistance. A plan of experiment based on the full factorial design has been performed. Analysis of variance (ANOVA) was used to determine the significant parameters and set the optimal level for each parameter. A correlation is developed between the process parameters and mechanical properties of the weld by multiple linear regression.**

***keywords*: Friction stir welding (FSW), Aluminum alloy 2024 and 7075, ANOVA**

1. INTRODUCTION

Friction-stir welding (FSW) is a relatively new technique developed by The Welding Institute (TWI) for the joining of aluminum alloys [1]. This process has been widely used in the area of space, aircraft, marine, fuel tank, and food saving industry for about a decade. Among the other methods of material welding processes, FSW has drawn a great a deal of researchers' attention because of its broad industrial applications. A rotating pin tool is used as stirrer to join two similar/dissimilar sheets [2]. Low distortion, high quality, lower residual stresses, fewer weld defects, and low cost joints are the main advantages of this method. The mechanical properties of the joints mainly depend on the welding parameters such as pin rotation speed, traverse speed and stirrer geometry. In order to increase the welding efficiency, mechanical properties of joints must be maximized and that of the defects minimized in the FSW process. Therefore, studying the mechanical properties and related significant factors would be effective to enhance the welding productivity and process reliability. A series of investigations have been conducted on modeling the FSW process with different approaches.

Okuyucu et al. [3] used the artificial neural networks (ANNs) for the calculation of the mechanical properties of welded Al plates using FSW method. It was found that the correlations between the measured and predicted values of tensile strength, hardness of HAZ, and hardness of weld metal were better than those of elongation and yield strength. Frigaard et al. [4] developed a numerical three- dimensional (3D) heat flow model for FSW of AA 6082-T6 and AA 7108-T79 aluminum alloys based on the method of finite differences. Buffa et al. [5] aimed two different analytic models to the determination of the average grain size due to continuous dynamic recrystallization phenomena in FSW process of AA 7075-T6 aluminum alloys have been implemented in a 3D FEM model and numerical analyses of the welding processes. The same authors developed a linear regression model to predict local effects of strain, strain rate, and temperature in FSW of AA6082-T6 alloy [6]. Chen and Kovacevic [7] used a three-dimensional model based on finite-element analysis to study the thermal history and thermo-mechanical process in the butt welding of aluminum alloy 6061-T6. The relationship between the calculated residual stresses of the weld and the process parameters such as tool traverse speed was presented. It was anticipated that the model could be extended to optimize the FSW process in order to minimize the residual stress of the weld. Ulysse [8] attempted to model the FSW process using 3D visco-plastic modeling. Parametric studies have been conducted to determine the effect of tool speed on plate temperatures and to validate the model predictions with available measurements. In addition, forces acting on the tool have been computed for various welding and rotational speeds. It was found that pin forces increased with increasing welding speeds, but the opposite effect was observed for increasing rotational speeds.

It seems that the literature contains various modeling techniques applied to the FSW process. Among these studies, parametric optimization of process and relative effect of each factor on welding mechanical properties is rather lacking. The objective of this work is to study the effect of welding parameters like tool rotation speed, traverse speed, on the tensile properties of the dissimilar Aluminum alloy AA2024 and AA7075 welds. This usually done by means of analysis of variance (ANOVA). Further regression analysis is used to establish the relationship between the factors and tensile strength.

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2. EXPERIMENTATION

The aluminum alloys 2024 & 7075 were investigated in this model. The thicknesses of these aluminum alloys are 5 mm and machined out in 150 mm lengths and 60 mm widths. Chemical composition of the alloys 2024 and 7075 are shown in the table 1 and table 2. AA2024 is copper based alloy and AA 7075 is a zinc based alloy. The alloys have been heat treated to T-6 condition temp (solution heat treated and artificially aged condition). The main parameters of FSW are properties of material to be welded, tool geometry, tool rotation, welding speed and angle between axis of tool and vertical milling machine tool holder axis. Hot worked tool steel (H-13) is used for welding purpose with a shoulder diameter of 15mm and screw thread pin diameter of 5mm is chosen for the experiments. The chemical composition of the tool is shown in the table 3. In this study tool rotation speed, traverse speed and shoulder diameter were selected as variable parameters and varied at three levels. Therefore 9 different parameters were used for welding based on the full factorial design of experiments. The experimentation parameters are shown in the table 4. The schematic representation of the friction stir welding process is shown in the figure 1. The experiments are done by a modified milling machine adapted for friction stir welding.

Table 1 Chemical composition of aluminum 2024 alloy

Component	Al	Cr	Cu	Fe	Mg	Mn	Zn	Ti	`Si	others
Weight (%)	90.47	0.10	3.8-3.9	0.50	1.2-1.8	0.3-0.9	0.25	0.15	0.50	0.15

Table 2 Chemical composition of aluminum 7075 alloy

Component	Al	Cr	Cu	Fe	Mg	Mn	Zn	Ti	`Si	others
Weight (%)	87.1-91.4	0.18-0.28	1.2-2.0	0.50	2.1-2.9	0.30	5.1-6.1	0.20	0.40	0.15

Table 3 Chemical composition of H-13 Hot worked tool steel

t	C	Mn	Si	Cr	Ni	Mo	V	Cu	P
Weight (%)	0.32-0.45	0.20-0.50	0.80-1.20	4.75-5.50	0.3	1.10-1.75	0.80-1.20	0.25	0.03

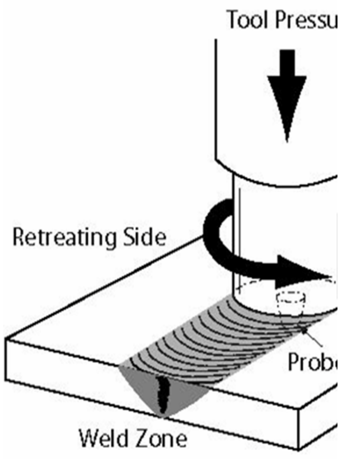

Fig 1.Schematic representation of the FSW process

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Table 4. Experimentation parameters used for the welding

Expt no	Tool rotation speed(rpm)	Traverse speed(mm/min)
1	600	8
2		12
3		20
4	800	8
5		12
6		20
7	1200	8
8		12
9		20

All the welded specimens are subjected for the tensile testing process. The specimens are prepared according to the ASTM E8 standard specifications. The specimens are cut to the standard dimensions in band saw cutting machine and milled using vertical milling machine.

3. RESULTS AND DISCUSSIONS

Effect of welding parameters on tensile strength

The tensile tests for the welded specimens are carried out in a micro tensile testing machine. The tensile tests are conducted in Small Industries Testing and Research Centre (SITARC). Tensile strength,

% elongation values are obtained for all samples. Figure 2 & 3 shows the variation of tensile properties of the joints welded at different speeds and tool rotational speeds. In welding the heat input plays an important role in the mechanical properties of the weldments. From the experimental results it is found that UTS increases steeply with increase in weld speed for TRS of 600 rpm. In this case the heat input is minimum, which consequently reduces the HAZ. The UTS increases gradually with increase in weld speed due to more heat input by increased in TRS which consequently enlarges HAZ for the TRS of 800 rpm.

Effect of the welding parameters on the elongation of the weld

In the Figure percentage of elongation from the tensile tested specimen were plotted against the weld speed. The percentage of elongation does not have considerable amount of variation in change with welding speed. However elongation increases with increase in TRS. The percentage of elongation for the welded plates changes from 4 to 10%.

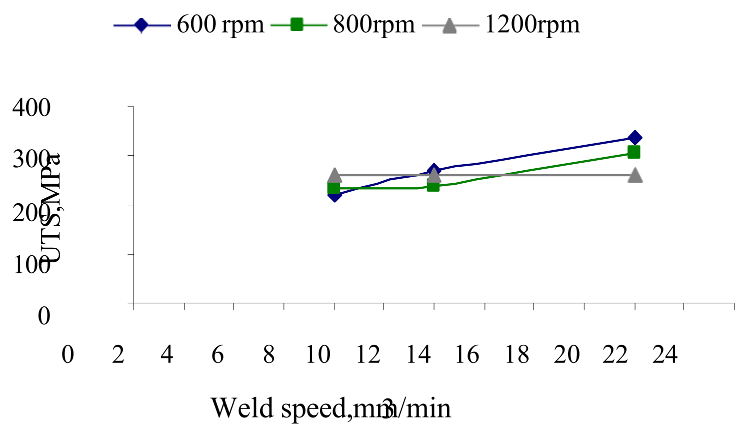

Fig. 2. Ultimate Tensile Strength of the welded plates

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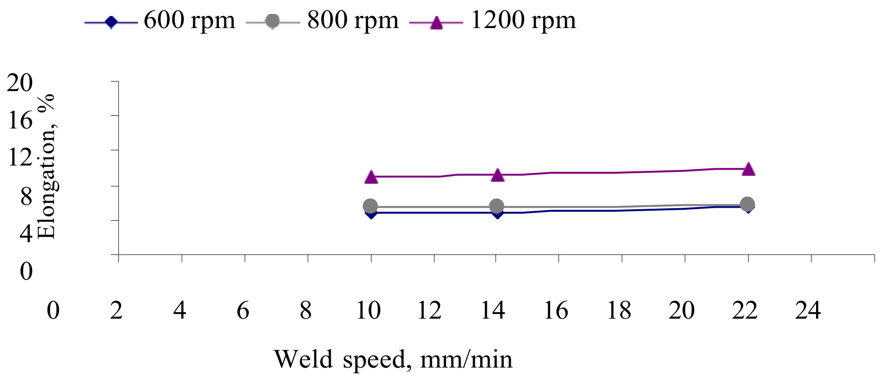

Fig. 3. Elongation % of the welded plates

4. REGRESSION MODEL RESULTS

Multiple Regression Model

The main objective of any regression analysis is to develop an empirical equation relating the dependent variable to the independent variables. In the present work, the main objective is to develop an empirical equation to predict the tensile strength, elongation and Vickers hardness of the welded plates. The independent parameters included in the regression model are welding speed and welding tool speed. The regression model attempted in this work is the multiple linear regressions, which is the process of developing an empirical relation for the dependent variables y, which is a linear function of two or more independent variables. For example, y might be a linear function of X_1, X_2 and X_3, as in

$y = a_0 + a_1x_2 + a_3x_3 + a_4x_4$……(1)

Such an equation is particularly useful when fitting experimental or numerical data where the variable being studied is often a function of two or more other variables. Such an equation is particularly useful when fitting experimental or numerical data where the variable being studied is often a function of two or more other variables.

Interactions

Interactions mean interdependence. Most of the factors have influence on results. If these factors all behave independent of each other, a plot of the main effect will not change no matter which other factor it is with. A single experiment will yield information about the factor that could be used at all times regardless of where the factor appears. Unfortunately, most factors you would deal with have some kind of interaction with other factors in the group. Here the factors are welding speed and tool rotation speed, so the interaction (I) can be formed as another factor with where I = welding speed X tool rotation speed.

The multiple linear regression models for the present problem with interactions is expressed as Dependent variable $= a_0 + a_1\,(WS) + a_2\,(TRS) + a_3\,(I)$

Where WS = welding speed, TRS = tool rotating speed, I = Interactions

The dependent variable values are obtained from the mechanical test results. The regression model is trained using the statistical software module of Minitab 15 from the results obtained from tensile testing. The empirical relation for the mechanical properties are obtained from the regression model are given by

Tensile properties	Regression equation
UTS, MPa	51.2 + 18.4(WS) + 0.159(TRS) - 0.0148(I)
Elongation, %	2.38 - 0.145(WS) + 0.00347 (TRS) + 0.000271 (I)

Table. 5 .Regression model equations for UTS and elongation %

The regression model was validated with the parameters WS = 8 mm/min and TRS = 1000 rpm for known experimental results. The table 6 represents the comparison and error in percentage. From the table, it is known that the regression model gives the results with 87% accuracy. The scatter plot of UTS and elongation % with regression model results are shown in Fig 6.

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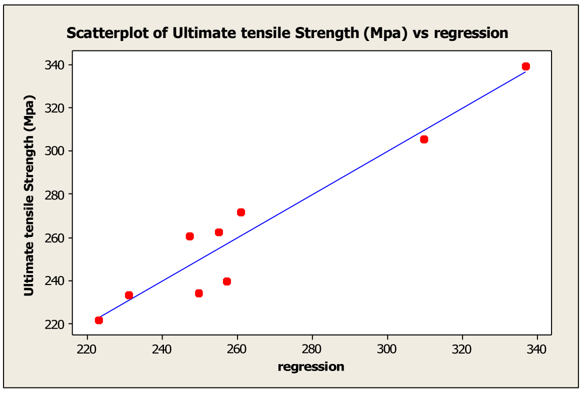
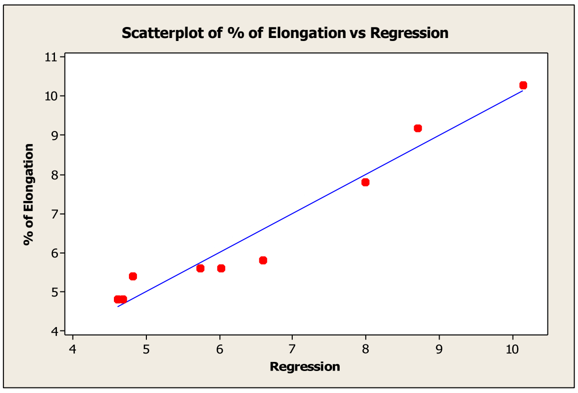
Material properties	Experimental results	Regression model results	Error in percentage
UTS, MPa	275.3	239	-13.19
Elongation, %	7.9	6.858	-13.19

Table.6. Comparison of results with experimental results



(a)



(b)

Fig.6(a),(b) Scatter plot for UTS and Elongation %

5. MICROSTRUCTURE AT DIFFERENT REGIONS OF FSW

The specimen for microstructure was prepared from the cross section perpendicular to the weld direction. The specimens were etched with HF. The microstructures were obtained in the zones like nugget, TMAZ, HAZ and base metal at the resolution of X500.

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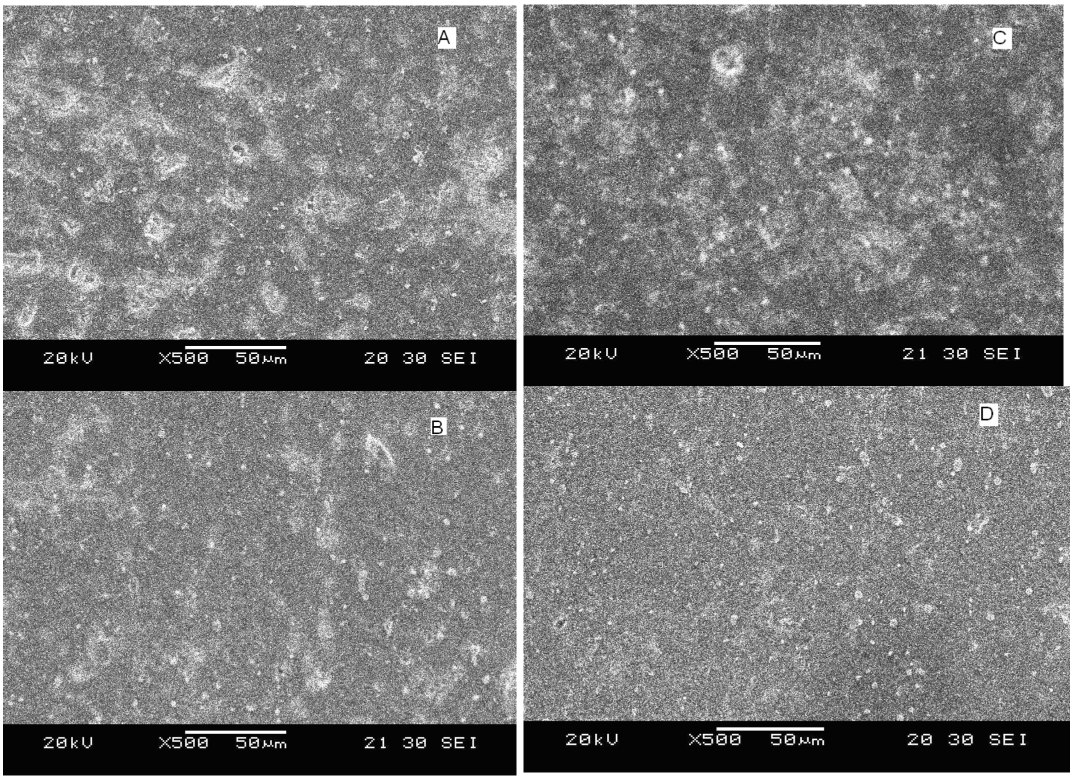
(a) (C)



(b) (d)

Fig .7(a),(b),(c),(d) Microstructure at different regions of FSW

Fig. 7(a).(b),(c),(d)shows an example of the microstructure at different regions of FSW. The microstructure of the parent metal exhibits alternatively more round grains (Fig.7 a). Discontinuous grain boundary precipitates are recognizable along the grain boundary regions. The microstructure of the thermo-mechanically and the heat affected zones does not appear significantly different from the microstructure of the parent metal, even though, in particular for the thermo-mechanically affected zones, the grains appear more visible (Fig.7.b) (Fig. 7.c). A similar discontinuous grain boundary phase distribution as for the parent metal is observed for the thermo-mechanically and the heat affected zones. The microstructure of the nugget zone have fine grain boundary due to the dynamic recrystallisation by the welding pin (Fig.7.d).

Intergranular Fracture

Intergranular fracture (also known as 'rock candy' fracture in structures with a coarse grain size,) is another low energy form of fracture that usually indicates either an embrittlement problem or a processing problem (quench cracking). It is important to remember that most forms of embrittlement (stress corrosion cracking, hydrogen, liquid metal) can occur by either cleavage or intergranular mechanisms (or even MVC in some cases), depending on the local stresses and the alloy and microstructure. In this work the SEM images were captured with magnification range of x250 and x500. The Fig.8 reveals that in the fractured zone of base metal the grain size is coarse which shows poor ductility of the material. The grain boundaries of the fractured area in base metal have long and irregular boundaries which show low ductility. In the Fig.9 the fractured zone at the weld metal has the fine grain size which shows that the weld area has more ductility than the base metal. The grain boundaries of the fractured area in weld metal have short and continuous boundaries which show more ductility compared to base metal.

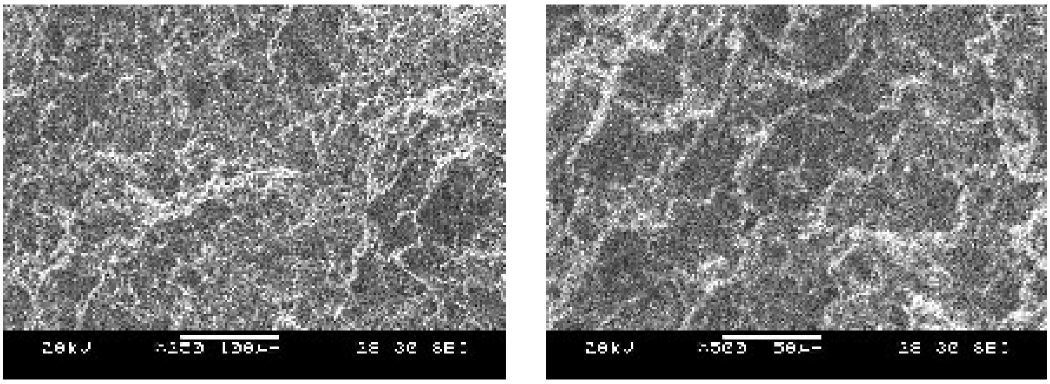


Fig 8 Microstructure of fractured area in base metal under X250 and X500

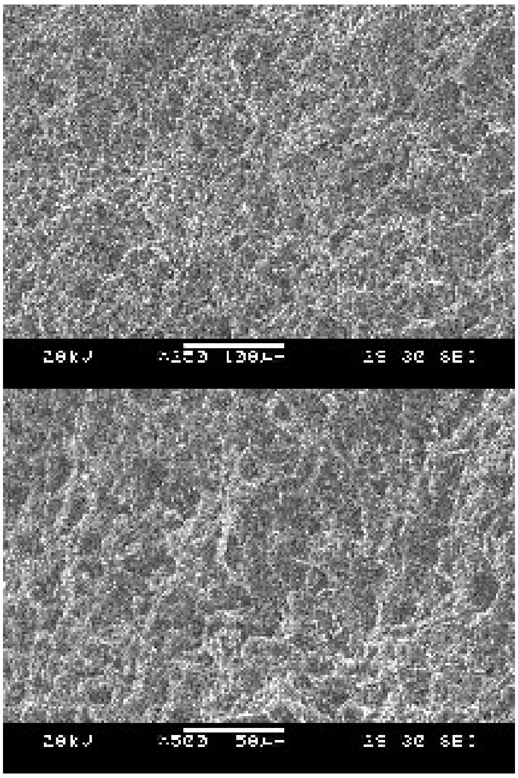


Fig 9 Microstructure of fractured area in weld zone under X250 and X500

6. CONCLUSIONS

Experimental trails were carried out by varying the parameters for the investigation of change in material properties. In this work nine welding trials were carried out for tensile testing. Welded samples were characterized by means of tensile strength, elongation. Microstructure of the welded samples was also investigated in this work. It is known that increasing the welding speed and decreasing the rotational speed of the tool reduces the heat input. Thus, increase in welding speed also increases the tensile strength while increasing TRS decreases the tensile strength. However, Increase in TRS causes more heat input consequently enlarges HAZ. The enlarged HAZ results in a low tensile strength. Furthermore, increasing the welding speed reduces the heat input and low heat used for predicting the mechanical properties without input causes a smaller HAZ.

Tensile test gives information about the elongation of the FSW samples. Here, again the amount of heat input plays an important role on the elongation properties of the FSW samples. The more heat input is the more elongation of the FSW samples. The sample welded with the 1200 rpm of the tool and 8 mm/min showed the largest elongation while the sample welded with the 600 rpm of the tool and 20 mm/min yielded the minimum elongation. Regression model was developed in this work and it can be used for the real time prediction of tensile strength, elongation for various welding speed and tool rotating speed without requiring experimental testing. It has been observed that the simulation results are 87 % accurate and they can be much loss in accuracy.

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