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Research on Effect of Process Parameter on Micro Hardness of Friction Stir Welded Aluminium Alloy [A6061] Joints

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Abstract: Friction stir welding (FSW) process is a promising solid-state joining process with the potential to join low-melting point material, particularly, aluminium alloy. The most attractive reason for joining aluminium alloy with this process is the avoidance of the solidification defects formed by conventional fusion welding processes. In this research article, an attempt has been made to develop an empirical relationship between FSW variables and Micro Hardness. A factorial design was used by considering three factor and eight trials, which enables to quantify the direct and interactive effect of three numeric factors, that is, tool rotational speed, welding speed, and shoulder diameter on the Micro Hardness. The developed relationship is useful for prediction of Micro Hardness in friction stir welded AA6061 aluminium alloy joints at 95% confidence level. It will also be helpful for selection of process variable to obtain the desired strength of the joint. Furthermore, the optimized capabilities in design-expert software were used to numerically optimize the input parameters.

Keywords: Friction-Stir Welding, Shoulder Diameter, Tool Rotational Speed, Micro Hardness, Aluminium Alloy [A6061]

I. INTRODUCTION

In many industrial applications steel is readily re-placed by non-ferrous alloy, in most cases aluminium alloys. Some of these materials combine mechanical strength comparable with structural steel and low weight, allowing for a significant reduction of weight. But the joining of aluminium alloys can sometimes cause a serious problem by the conventional welding process. The difficulty is often attributed to the solidification process and structure including loss of alloying elements and presence of segregation and porosities. Friction stir welding (FSW) offers an alternative through solid-state bonding, which eliminates all these problems of solidification associated with the conventional fusion welding processes. The dependence on friction and plastic work for the heat source precludes significant melting in the work piece, avoiding many of the difficulties arising from a change in states, such as changes in gas solubility and volumetric changes, which often plague fusion welding processes. Further, the reduced welding temperature makes possible dramatically lower distortion and residual stresses, enabling improved fatigue performance and new construction techniques and making possible the welding of very thin and thick materials. FSW has also been shown to eliminate or dramatically reduce the formation of hazardous fumes and reduces energy consumption during welding, reducing the environmental impact of the joining process. Further, FSW can be used in any orientation without regard to the influence of gravitational effects on the process. These distinctions from conventional arc welding processes make FSW a valuable manufacturing process with undeniable technical, economic, and environmental benefits. The process and the terminology are schematically explained in Fig: 1.1. The welding process parameters such as tool rotational speed, welding speed, and pin diameter play a major role in deciding the weld quality. In general, the solid-state nature of the FSW process, combined with its unusual tool and asymmetric nature, results in a highly characteristic microstructure. The microstructure can be broken up into the following zones as explained in Fig: 1.2.

- The stir zone (also nugget, dynamically recrystallised zone)
- The flow arm zone
- The thermo-mechanically affected zone (TMAZ)
- Heat-affected zone (HAZ)

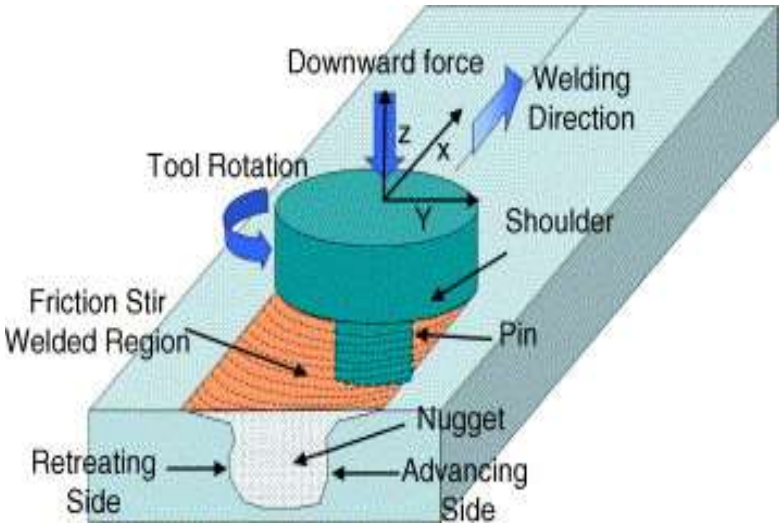

Fig: 1.1: Process & Terminology of FSW

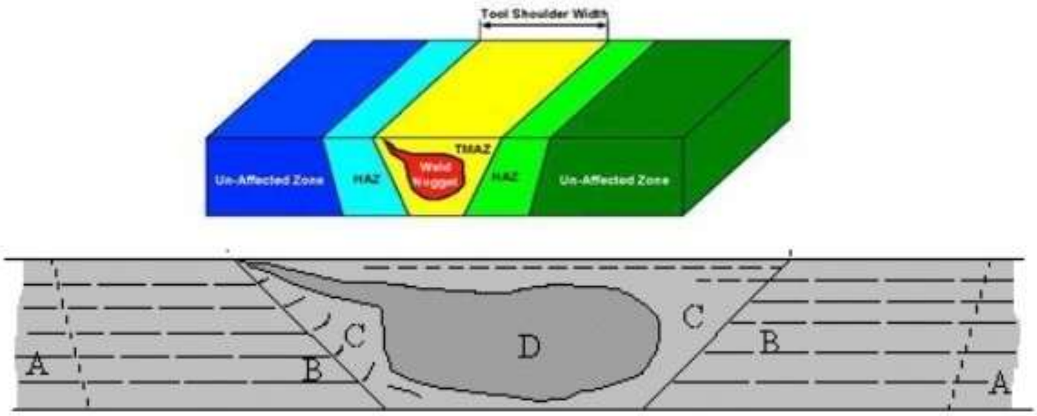

Fig: 1.2: Microstructure Zones

The solid-state nature of FSW leads to several advantages over fusion welding methods as problems associated with cooling from the liquid phase are avoided. Issues such as porosity, solute redistribution, solidification cracking and liquation cracking do not arise during FSW. In general, FSW has been found to produce a low concentration of defects and is very tolerant of variations in parameters and materials.

II. LITERATURE REVIEW

William (2002) examined in the present study, the global and local mechanical response of friction stir welded AA2024 experimentally and numerically. Full field strain measurements are obtained on transversely loaded tensile specimens via the digital image correlation technique. Assuming an iso-stress configuration, local constitutive data were determined for the various weld regions and used as input for a 2-D finite element model.

Liu (2003) studied the relations between welding parameters and tensile properties of the joints, in order to demonstrate the friction stir weldability of the 2017-T351 aluminium alloy and determine optimum welding parameters, the experimental results showed that the tensile properties and fracture locations of the joints are significantly affected by the welding process parameters.

Chen et al. (2006) studied the friction stir welding (FSW) of 2219-O and 2219-T6 aluminium alloys to investigate the effects of the base material conditions on the FSW characteristics. The experimental results indicated that the base material condition has a significant effect on weld morphologies, weld defects, and mechanical properties of joints. In the 2219-O welds, no discernible interface exists between the stir zones (SZ) and the thermal mechanically affected zone (TMAZ), and weld defects are liable to form in the lower part of the weld. In the 2219-T6 welds, there is the visible interface between the SZ and the TMAZ, and a weld nugget with an “onion ring” like morphology clearly exists.

Simar et al. (2008) investigated the effect of the welding speed on the microstructure, local and overall mechanical properties of friction stir welded joints of the aluminium alloy 6005A-T6. The fine hardening precipitation within the heat-affected zone has been characterized by differential scanning calorimetry (DSC) and transmission electron microscopy (TEM).

Lakshminarayanan et al. (2008) applied Taguchi approach to determine the most influential control factors which will yield better tensile strength of the joints of friction stir welded RDE-40 aluminum alloy. In order to evaluate the effect of process parameters such as tool rotational speed, traverse speed and axial force on the tensile strength of friction stir welded RDE-40 aluminium alloy, Taguchi parametric design, and optimization approach was used.

Bitondo (2010) investigates in this work the influence of the Friction Stir Welding (FSW) parameters on the mechanical properties AA 2198 T3 welds. For this purpose, a full-factorial experimental design was conducted. The observed responses are an ultimate tensile strength (UTS) and yield strength (YS). The factors under investigation are tool rotational speed (N) and welding feed (Va). In order to estimate the influence of the heat transfer transient phase on the mechanical properties of the weld, besides these classical welding parameters, a position parameter defining the relative distance of the specimens from the welding run-in and run-out is considered. Analysis of variance (ANOVA), main effect plot and desirability function technique were used to determine the significant parameters and set the optimal level for each parameter. A regression equation was derived to predict each output characteristic.

From the available literature it was found that previous researchers have studied the effect of welding parameters on desired response using the conventional method of varying one parameter at a time, though popular, does not give any information about interaction amongst the parameters. The effort has been made to investigate the individual and combined effect of welding parameters on mechanical and metallurgical properties of the friction stir welded joints of the aluminium alloy. In addition, interactions between two or more parameters can also be quantified, which is not possible with the conventional experimental approach.

III. EXPERIMENTAL DETAIL

Design of Experiment

A two level factorial design of ($2^3 = 8$) eight trials, which is a standard statistical tool to investigate the effects of a number of parameters on the required response, was selected for determining the effect of three independent direct welding parameters. The commonly employed method of varying one parameter at a time, though popular, does not give any information about interaction among parameters. The selecting of two level factorial design also helped in reducing experimental runs to the minimum possible. With the help of trial experiments and literature review, Tool rotation speed, welding speed, and shoulder diameter were identified as critical welding variables for carrying out the experiment.

Selection of Two Levels of Welding Variables

The working range covering the lowest and the highest level of the direct welding parameters were carefully selected by carrying out the trial runs so as to maintain defect free friction stir welding. The direct and indirect parameters except under consideration were kept constant. The upper level was coded as (+1) and lower level as (-1) or simply (+) and (-) for the factors with a continuous determination region, this can always be done with the aid of transformation with in the variation interval.

$$X_j = (X_{jn} - X_{jo})/ J_j \text{...(1)}$$

Where X_j, X_{jn}, and X_{jo} are the coded, natural and basic value of the parameter respectively. J_j and j are the variation and number of parameters respectively. The units, symbols used and limits of welding parameters are given in Table 3.1.

Table3.1 Welding Parameters used and their Limits

Parameters	Units	Symbols	Lower limit	Upper limit
Tool Rotational Speed	**RPM**	**N**	**1200**	**1500**
Welding Speed	**Mm/min**	**S**	**40**	**60**
Shoulder Diameter	**Mm**	**D**	**18**	**21**

Development of Design Matrix

The design matrix developed to conduct the eight trials runs of 2^3 fractional factorial designs as given in Table 3.2. The signs under the columns 1, 2, 3 were arranged in standard Yate's order.

Table 3.2 Design Matrix

Sl. No	N 1	S 2	D 3
1	+	+	+
2	-	+	+
3	+	-	+
4	-	-	+
5	+	+	-
6	-	+	-
7	+	-	-
8	-	-	-

Table 3.3: Experimental Results

S. No.	Run No.	Tool Rotational Speed	Welding Speed mm/mim	Shoulder Diameter (mm)	Micro Hardness Hv
1	5	-1	-1	-1	70
2	14	-1	-1	-1	71
3	20	-1	-1	-1	70
4	19	1	-1	-1	78
5	22	1	-1	-1	79
6	4	1	-1	-1	78
7	10	-1	1	-1	60
8	21	-1	1	-1	61
9	2	-1	1	-1	62
10	18	1	1	-1	75
11	6	1	1	-1	74
12	8	1	1	-1	75
13	15	-1	-1	1	70
14	7	-1	-1	1	69
15	1	-1	-1	1	69
16	16	1	-1	1	80
17	24	1	-1	1	79
18	12	1	-1	1	80
19	9	-1	1	1	60
20	23	-1	1	1	59
21	11	-1	1	1	61

22	3	1	1	1	68
23	13	1	1	1	68
24	17	1	1	1	69

Developed Model

Developed models could be obtained by putting the values of the regression coefficients obtained from equation (4) in the selected model,

$Y = b_0 + b_1N + b_2S + b_3D + b_{12}NS + b_{13}ND + b_{23}SD$ …………………... (4)

Checking the Adequacy of the Developed Model

The adequacy of the model was determined by the analysis of variance technique. The regression coefficients were determined by the method of least square, from which the F-ratio for the polynomial was found. The variance of the response and the adequacies were calculated. The 'F'- the ratio of the model were compared with the corresponding 'F'- ratio from the standard table and it was found that the model is adequate within 95% level of confidence, thus justifying the use of assumed polynomials.

After calculating the coefficients of the model, it must be tested for its fitness. Thus adequacy of the model was tested using analysis of variance technique. For this, the variance of optimization parameter (S^2y) was determined. For two repetitions of each trial the formula is:

$S^2y = 2\sum^N_{i=1}(\Delta Y^2)/N$ ……………………………………….(5)

Where $\Delta Y^2 = (Y_{iq} – Y_m)^2$

Y_m = Arithmetical mean of repetitions (response in the repetitions)

Y_{iq} = Value of response in a repetition trial

N = Number of observations

i= No. of trials

q=No. of repetitions

Further, the variance of adequacy, also called residual variance was determined by using following formula:

$S^2ad = \sum^N_{i=1} \Delta (Yp – Ym)^2/f$……………..…………………..(6)

Where

S^2_{ad} = Variance of adequacy

Y_m = Observed or Measured response

Y_p = Estimated/Predicated value of response (obtained from model)

f = N-(K+1) (Degree of freedom)

$\sum^N_{i=1}$ = residual sum of square

k = Number of independently controllable variables.

The ratio of variance of adequacy to the variance of optimization parameter gave Fisher ratio:-

$F = S^2ad/ S^2y$…………….…………………………..(7)

F-values, thus, obtained and denoted as (F_m) were compared from the table value as (F_t). It was found that the model was adequate at 95% level of significance thus justifying the use of the assumed polynomial.

Checking the Significance of Coefficients of Model

The statistical significance of the coefficients can be tested by applying's' test. The level of significance of a particular parameter can be assessed by the magnitude of the't' value associated with it. Higher the value of't', the more significant it becomes. 't' values for the given coefficients of the models were calculated using following formula:

$t = |b_j|/S_{bj}$…………………………………………. (8)

Where,

$|b_j|$ = absolute value of coefficients

S_{bj} = standard deviation of coefficients

$S_{bj} = \sqrt{S^2y/N}$

Calculated 't' values were compared with the t-table value and statistically insignificant terms of the models were dropped. The value of't' from the standard table for eight degrees of freedom and 95% confidence level is 2.306. Coefficients having calculated 't' value less than or equal to 't' value from the standard table for eight degree of freedom and 95% confidence level, are the members of reference distribution i.e. due to the intrinsic variations of the experimentation and hence, they cannot be significant.

Final Model

The final model could be obtained by dropping statistically in-significant terms from the developed models.

Experimentation

In experimentation first step was a selection of material for which 6061 aluminium alloy was selected and chemical composition and mechanical properties of the selected material are shown in Table 3.8 and Table 3.9 respectively. The friction stir welding process was performed on a vertical milling machine. The specially designed fixture was clamped on bed of vertical milling machine. The tool was mounted on the vertical spindle. Then two prepared aluminium pieces were clamped into the fixture. Then after some time, when there was sufficient heating was achieved due to friction between tool and plates, the bed was given automatic feed, along with the joint direction. Thus the welding was achieved. 8 experiments were performed as per the as per design matrix. The trials were repeatedly three times for determining the adequacy of mathematical models. Thus total 24 experiments were performed.

Table 3.8 Chemical Composition of Base Material

Si	Fe	Cu	Mn	Mg	Al
0.57	0.35	022	0.12	1.1	Bal

Table 3.9 Mechanical Properties of Base Material

Ultimate tensile strength (MPa)	Elongation	Hardness Hv
280	20	100

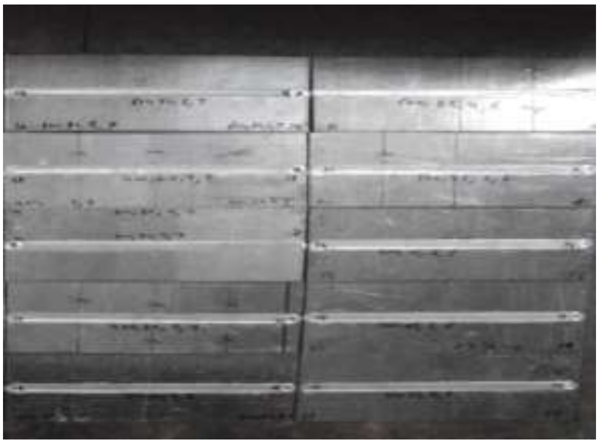

Fig: Friction Stir Welded Specimens

Micro Hardness Test

This test is performed to measure the hardness at different zones of the weld. It is a useful tool to help identify the weak zones of the weld. The readings were taken across the weld joint. The samples were polished with emery papers. Then these samples were fine polished on the surface polishing machine. The alumina powder paste and then diamond paste was used to get a mirror like surface. Total 15 readings were taken across the weld joint each 1mm apart under 1N load for 15 seconds.

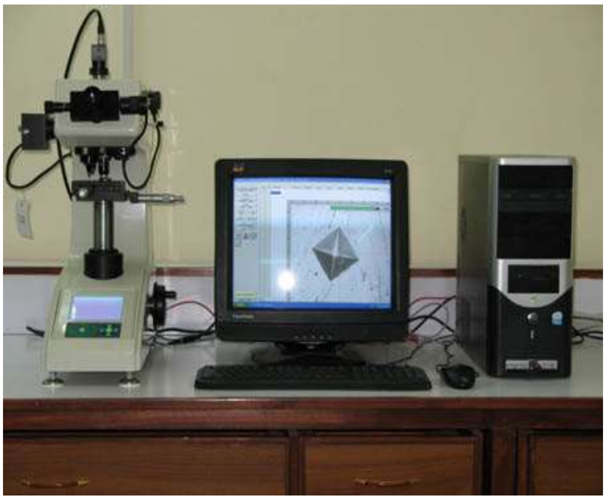

Fig: - Micro Hardness Testing Setup

IV. RESULTS & DISCUSSIONS

Direct Effect of Process Parameters on Tensile Strength

The Model F-value of 102.23 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case, N, S, D, SD are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), the model reduction may improve your model. The "Lack of Fit F-value" of 44.08 implies the Lack of Fit is significant. There is only a 0.01% chance that a "Lack of Fit F-value" this large could occur due to noise. After dropping the in-significant co-efficient the final model for micro hardness is given below.

Micro hardness= 70.21+5.04N-4.21S-0.88D-0.96SD

The "Pred R-Squared" of 0.9462 is in reasonable agreement with the "Adj R-Squared" of 0.9635; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 28.206 indicates an adequate signal. This model can be used to navigate the design space. Scatter diagrams, which show the predicted and the observed values of responses, were also drawn so as to test the validity of these models. A good agreement was found to exist between the actual and the predicted responses of percentage elongation as shown in Fig. 4.9 and Fig 4.10 respectively.

Table: ANOVA for Selected Factorial Model Micro hardness

Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F	Significant
Model	1083.92	6	180.65	102.23	< 0.0001	
N-tool rotational speed	610.04	1	610.04	345.21	< 0.0001	Yes
S-Welding speed	425.04	1	425.04	240.52	< 0.0001	Yes
D-Shoulder diameter	18.38	1	18.38	10.40	0.0050	Yes
NS	5.04	1	5.04	2.85	0.1095	No
ND	3.38	1	3.38	1.91	0.1849	No
SD	22.04	1	22.04	12.47	0.0026	Yes
Residual	30.04	17	1.77			

Lack of Fit	22.04	1	22.04	44.08	< 0.0001	Yes
Pure Error	8.00	16	0.50			
Cor Total	1113.96	23				

Table 4.4 Summary Statistics of the Model for Micro Hardness

Std. Dev.	1.33	R-Squared	0.9730
Mean	70.21	Adj R-Squared	0.9635
C.V. %	1.89	Pred R-Squared	0.9462
PRESS	59.88	Adeq Precision	28.206

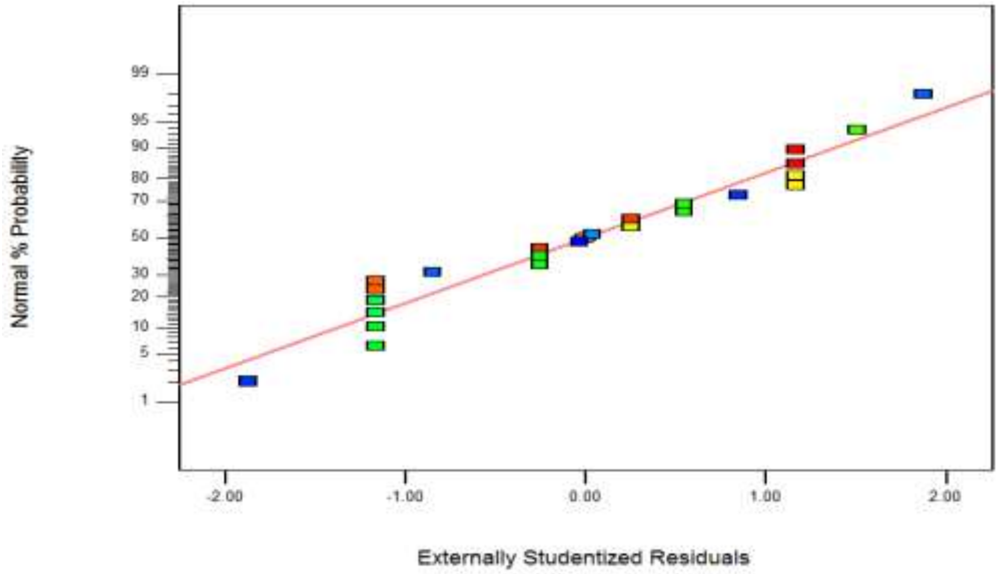

Fig.4.9 Normal Plot of Residuals for Percentage Elongation

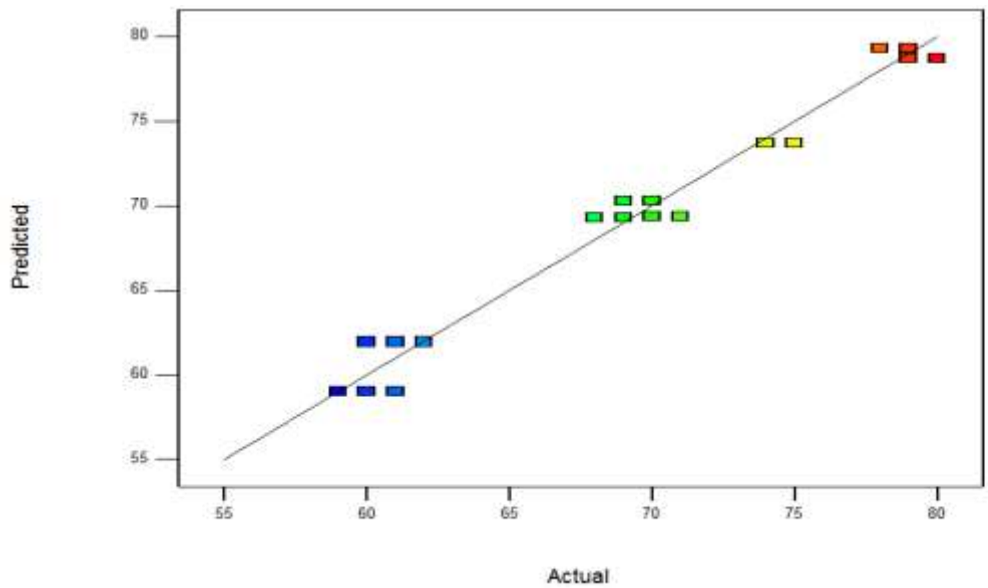

Fig.4.10 Predicted v/s Actual Plot for Percentage Elongation

Effect of Tool Rotational Speed on Micro Hardness

The effect of tool rotational speed on micro hardness has been presented in Figure 4.11 As shown in the Figure, the micro hardness of the joint increases with increase in the tool rotational speed. The micro hardness of the joint was 66 Hv at the tool rotational speed 1200 rpm. The micro hardness of the joint was increased and reached 74 Hv when the tool rotational speed was reached at 1500 rpm. As the tool rotational speed was increased heat input in the stir zone was improved and resulting in fine grains which may be the reason of higher micro hardness at higher welding speed.

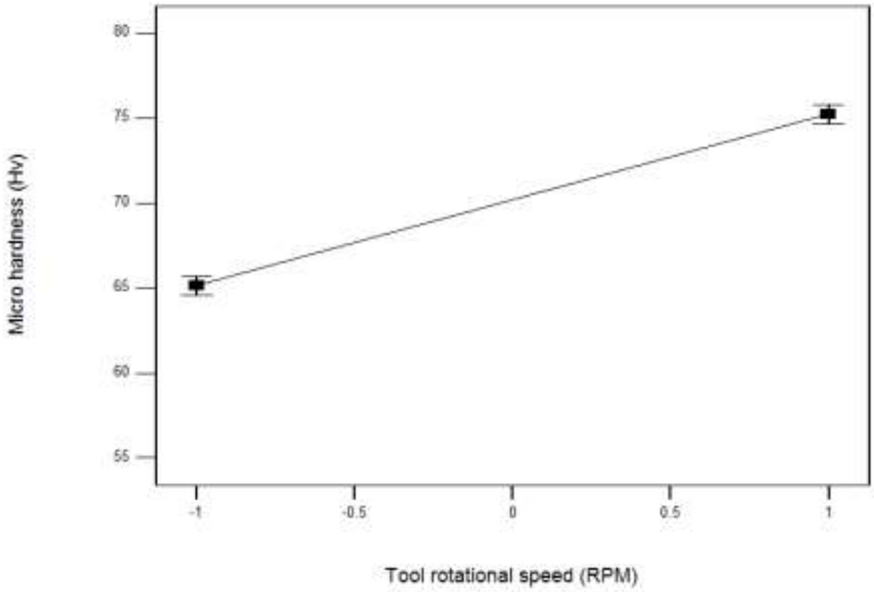

Fig.4.11 Effect of Tool Rotational Speed on Micro Hardness

Effect of Welding Speed on Micro Hardness

The effect of welding speed on micro hardness has been presented in Figure 4.12 As shown in the Figure, the micro hardness of the joint decreases with increase in the welding speed. The micro hardness of the joint was 75 Hv at the welding speed of 40 mm/min. The micro hardness of the joint was decreased and reached 64 Hv when the welding speed was reached at 60 mm/min. The micro hardness of the joint was higher at lower welding speed due to sufficient heat input in the stir zone by the proper interaction between the tool and workpiece, resulting in fine grains in the stir which may be the reason of higher micro hardness in the joint at lower welding speed.

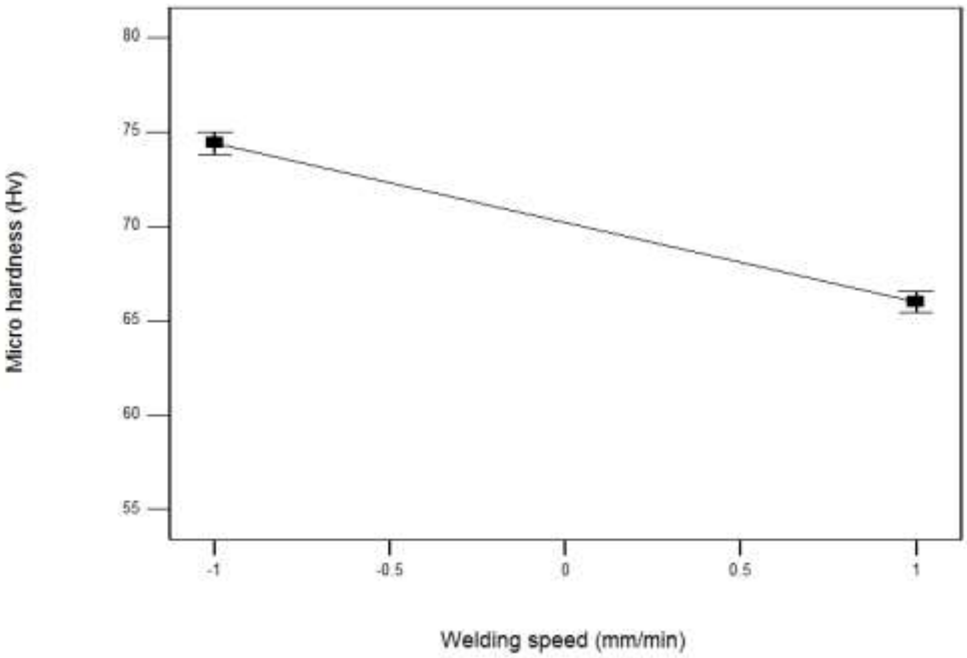

Fig.4.12 Effect of Shoulder Diameter on Micro Hardness

Interaction Effect of Welding Speed and Shoulder Diameter on Micro Hardness

The interaction effect of welding speed and shoulder diameter on the micro hardness is presented in Figure 4.14 As shown in the figure, at the lower level of the welding speed the micro hardness of the joint was higher with both shoulder diameters. By increasing the welding speed the micro hardness of the joint was reduced with both shoulder diameters.

From the response surface, micro hardness at any combination of the two parameters welding speed and shoulder diameter can be predicted. As shown in fig. 4.15

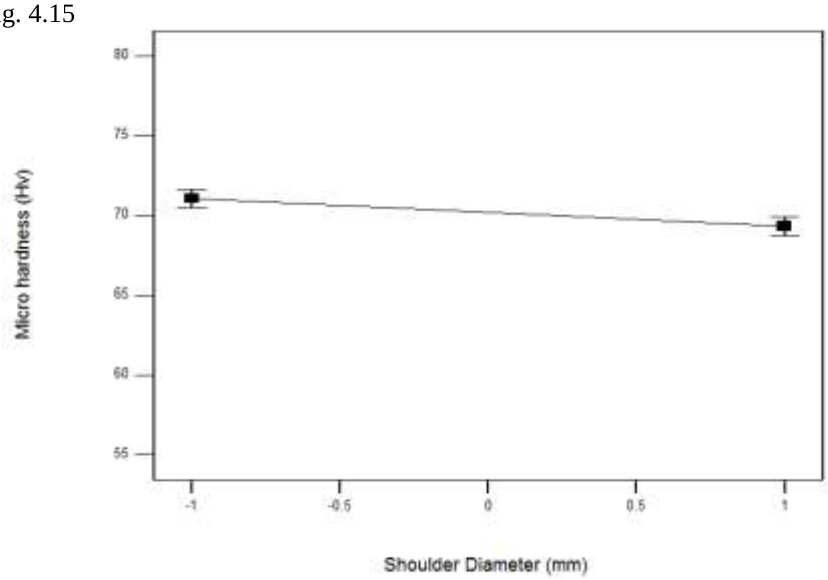

Fig.4.13 Interaction Effect of Welding Speed and Shoulder Diameter on Micro Hardness

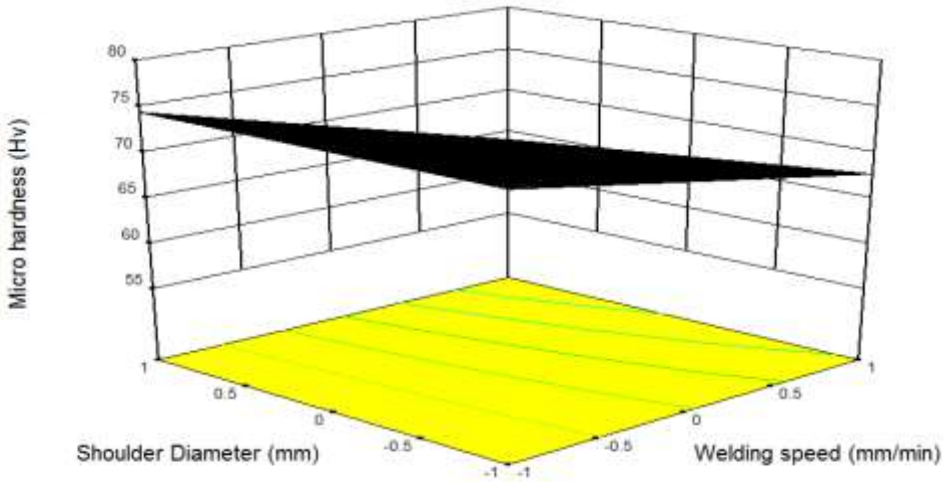

Fig.4.15 3 D Responce Surface Plots For Effect of Shoulder Diameter and Welding Speed on Microhardness

V. CONCLUSIONS

- As per investigation increasing in the tool rotational speed increased heat input in the stir zone was improved and resulting in fine grains which may be the reason of higher micro hardness at higher welding speed.
- By increasing the welding speed the micro hardness of the joint reduces with both shoulder diameters.
- Prediction of the Micro Hardness at any combination of the two parameters welding speed and rotational speed can be done.
- Proposed models are adequate at 95% confidence level, thus justifying the use of assumed polynomials.

VI. FUTURE SCOPE OF WORK

- Effects of welding parameters on microstructure, forces, and energy inputs of weldment may be investigated.
- Effects of welding parameters on other mechanical properties like bending strength, fatigue behaviour can be studied.
- Dissimilar metals can be joined with help of FSW process and study of welding parameters can be done.
- FSW process can be studied for suitability for welding other materials like copper, magnesium, titanium, steel etc.

REFERENCES

1. K. Elangovana, V. Balasubramanianb, “Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy”, Journal of materials processing technology 2 0 0 (2 0 0 8) 163–175
2. Kumar K, Satish V, (2008) “The role of friction stir welding tool on material flow and weld formation” Materials Science and Engineering: A, 485 (1-2). pp. 367-374.
3. L. Karthikeyan, V.S. Senthil Kumar, D. Viswanathan, S. Natarajan, (2007) “Effect of Low Feed Rate FSP on Microstructure and Mechanical Properties of Extruded Cast 2285 Aluminium Alloy”, Journal of Material Science Technology, 23, p. 614-618.

4. Muthukumaran S. and Mukherjee s. K. (2007), " First mode offers compactness in friction stir welding process", welding –productivity and quality (WPQ-2007), pp. 481-487
5. R. Nandan, T. DebRoy, H.K.D.H. Bhadeshia Recent advances in friction-stir welding – Process, weldment structure and properties Progress in Materials Science 53 (2008) 980–1023
6. Schmidt H. N. Dickerson T. L. and Hattel J. H. (2006) "Material flow in butt friction stir welds in AA2024-T3" acta Materialia, 54, pp. 1199-1209.
7. Schmidt H. N. Dickerson T. L. and Hattel J. H. (2006) "Material flow in butt friction stir welds in AA2024-T3", Acta Materialia, vol. 54, 2006, pp. 1199-1209.
8. Tomotake Hirata, Taizo Oguri, Hideki Hagino, Tsutomu Tanaka, (2007) "Influence of friction stir welding parameters on grain size and formability in 5083 aluminium alloy" Materials Science and Engineering A 456, pp 344–349.
9. William D. Lockwood, Borislav Tomaz, A.P. Reynolds," Mechanical response of friction stir welded AA2024: experiment and modeling", Materials Science and Engineering A323 (2002) 348–353
10. Yingchun Chena, Huijie Liu, Jicai Feng (2006) "Friction stir welding characteristics of different heat-treated-state 2219 aluminium alloy plates" Materials Science and Engineering A420, pp 21–25
11. Z. Zhang, H.W. Zhang Numerical studies on the effect of transverse speed in friction stir welding Materials and Design 30 (2009) 900–907
12. Ankur Gill, Gurpreet Singh Chahal (2017). **"**Effect of Process Parameter on Mechanical Properties of Friction Stir Welded Aluminium Alloy Joints Using Factorial Design**''.**

