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Genetic Algorithm-Based Optimization of Friction Stir Welding Process Parameters on Aa7108

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***Abstract:** This research paper deals with the characterization of friction stir welding aluminium 7108 with twin stir technology. The coupons of the above metal were friction stir welded using a cylindrical pin with counter-rotating twin stir technology using at constant speed 900, 1200, 1500,1800 with four different feed rates of 30,50,70,90 mm/min. Microstructure examination showed the variation of each zone and their influence on the mechanical properties. Also, tensile strength and hardness measurements were done as a part of the mechanical characterization and correlation between mechanical and metallurgical properties and deduced at the speed of 1500 rpm. Friction stir welding process parameters such as tool rotational speed (rpm), tool feed (mm/min) were considered to find their influence on the tensile strength (MPa) and hardness (HRB). A genetic algorithm (GA) was employed by taking the fitness function as a combined objective function to optimize the friction welding process parameters to predict the maximum value of the tensile strength and hardness. The confirmation test also revealed good closeness to the genetic algorithm predicted results and the optimized value of process parameters for different weights of the tensile and hardness have been predicted in the model.*

***Keywords:** Friction Stir Welding, Design Of Experiment, Optimization, Ultimate Tensile Strength, Hardness, Genetic Algorithm.*

I. INTRODUCTION

Friction stir welding was invented in 1991 at the welding institute (TWI) of the United Kingdom [1]. It is a solid-state material joining process and it was applied for different material copper, lead, titanium, magnesium, zinc, plastics, mild steel, nickel alloy etc. [1]. In this welding, two pins are rotated at a constant speed and feed between two plates to be joined. This welding is different from another welding [1]. In this welding, the material reaches the plasticization position and then after welding generated between two plates [2]. The main difficulty in this type of material is that cannot be welded with fusion welding because it is susceptible to welded with solidification, porosity, lack of fusion, cracking and harmful fumes. To overcome the difficulties during the welded of the aluminium alloys using fusion welding any one of the available solid-state welding processes has to be used.

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One important thing is that this welding material not melted. This welding is mostly definitions are self-explanatory, but advancing and retreating side orientations require knowledge of the tool rotational and tool transverse speed [1]. The friction stir welding figure shown in the below figures 1. But in the twin tool stir technology two tools rotated in the opposite direction to the weld generated gives in figure 1 (I).

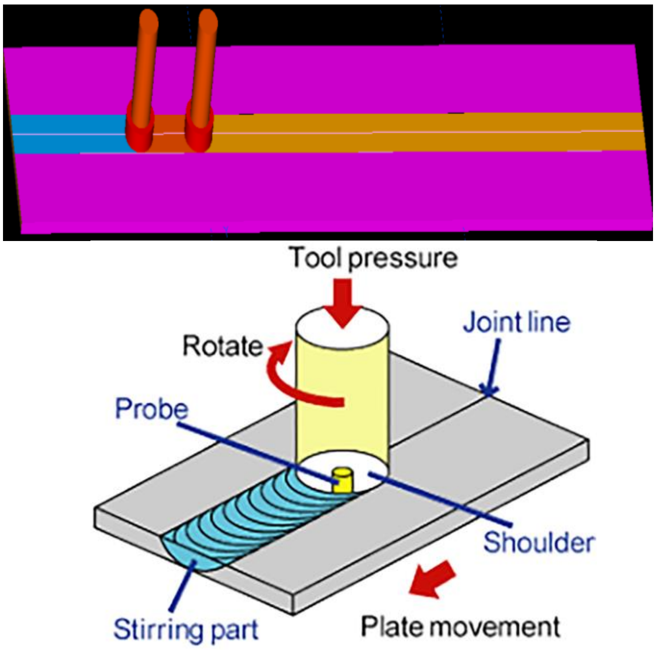

Figure 1 Friction Stir welding (I) Twin tool setup (II) single tool [1]

Among the available friction stir welding process used in many industries. In this process the heat is generated is higher compared to the single tool. Dinaharam et al. inspected the two dissimilar material on the wrought and cast alloy and gives an important point is that placed at the advancing side material is important at the time of the rotational speed increased [5]. H.K. Mohanty et al. found the tool probe geometry is very responsible for the weld quality and tensile strength and elongation increase with increase the welding speed [8]. Luis Trueba et al. examined tool shoulder highly effect on the defect-free joint also tool pin is important parameters on the weld joint strength [14]. Chinmay Shah et al. observed that the composite material highest contribution on the UTS is transverse speed (35.09%), Tool Geometry (18.29%) and tool rotational speed (5.97%) [15]. Ravi Shankar et al. examined that the lower feed rate increase the hardness and lower speed increase the tensile strength [17].

Shalin et al. found that tool pin profile is an important factor in this welding and they used the cylindrical, square and tapered tool but observed that the tapered is best because of the contact area increase and tensile is increased [18]. Subhasini et al. analyzed that the tapered cylindrical threaded tool used with tool rotational speed 1000 and 1200 rpm to perform tensile, hardness and bending test and 1200 rpm is best for this tool [20]. Ratnam et al. investigated on the twin pin tool geometry two dissimilar material with observing the surface morphology of the twin spin conical present the defect-free weld joint [23]. S.P. Sundarsinh et al. found that the feed rate used between 90 mm/min to the 210mm/min and rpm between the 1000 to 2000 rpm also gives the ignition mapping to avoid the flares and ring of the fire during the joint. In 1000 rpm and 90 feed cannot generate any spark and feed is increased to 150 to 210 mm/min so flares and ring of fire generated respectively [24]. Sharma et al. observed that the welding on the 7075 material has good tensile strength reach to user input parameters as 1750 rpm tool rotational speed and 45 mm/min feed are the best for the output value [29].

II. EXPERIMENTAL SETUP AND TOOL PROCESS PARAMETERS

2.1 Experimental setup

The aluminium alloy 7108 are welded using the JYOTI VMC 850 machine. In this welding, we can generate twin stir technology (counter-rotating twin tool) to use the welding of the AA7108. A VMC machine with a tool image shown in the below figure. VMC bed dimensions 1000×530 mm and 8000 rpm and spindle power 10.5 KW to 1305 KW and feed 10 m/min. maximum load on the table is 500 Kgf.

Figure 2 (I) Jyoti VMC 850 set up (II) Twin tool setup

2.2 Process parameters

The coupons to be welded are cut to a dimension of 100×200×6 mm and a special clamping arrangement can be used to all the degree of freedom. In this welding cylindrical tool is used and two parameters were welded of tool rotational speed (rpm) and Tool feed (mm/min). In this weldment, AISI H13 tool steel used as a tool material provide the chemical composition of the H13 in the given table below and Tool specification is given in to below table. A continuous drive friction stir welding machine spindle speed between 1 to 4800 rpm is employed to accomplish the welding process. The most influential parameters in friction stir welding are rotational speed, Tool feed, friction pressure, etc. In this work full factorial was used to study the impact of the process parameters over the mechanical and metallurgical properties of the friction welded joint. This work selected the process parameters as per the machine specification and literature review. In this work pilot test was run and then after selecting the best range of the process parameters shown in the table.

Table 1. Chemical composition of H13 tool steel

H-13	C	Si	Mn	P	S	Cr	Mo	V
%	0.380	1.05	0.48	0.015	0.004	4.88	1.270	0.900

Table 2 Tool specifications

Descriptions	Shank Length (mm)	Shank diameter (mm)	Shoulder length (mm)	Shoulder diameter(mm)	Pin length	Pin diameter (mm)
Dimensions	60	10	15	20	5.9	6

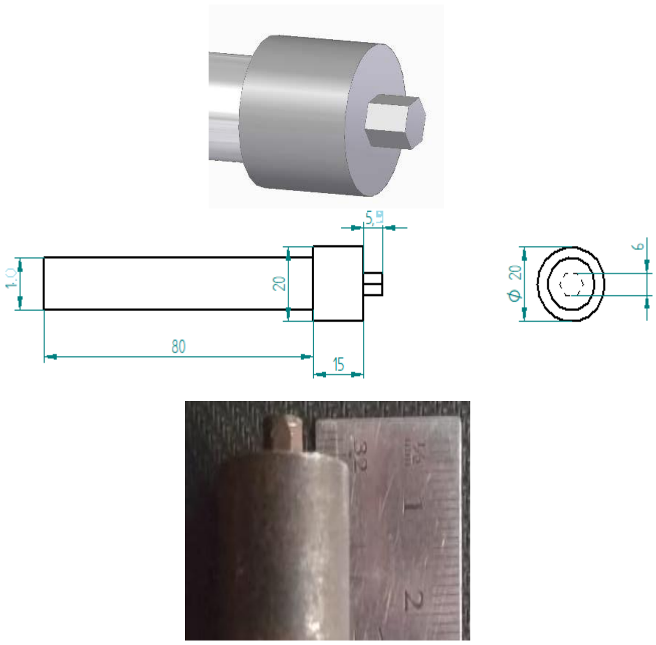

Figure 3 Hexagonal pin design

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Table 3. Selected process parameters

Process parameters	Level I	Level II	Level III	Level IV
Rotational speed (rpm)	900	1200	1500	1800
Tool feed (mm/min)	30	50	70	90

III. TESTING

3.1 Tensile Testing

A 15-ton maximum loading capacity Universal testing machine (UTM) was used to perform the tensile tests on the friction welded pieces of the AA7108 shown in the below figure(). The tensile test pieces were developed on the VMC 850 with a 3mm cutter used and with a continuous supply of the coolant and it cannot affect the cutting process. Secondly, it can be prepared according to the ASTM standards for the size shown in the below figure no(4). The Ultimate tensile strength value was collected and stored in the table.

(I) Tensile specimen

(II) tensile specimen after fracture

Figure 4 (I) Tensile specimen before testing (II) tensile specimen breakdown.

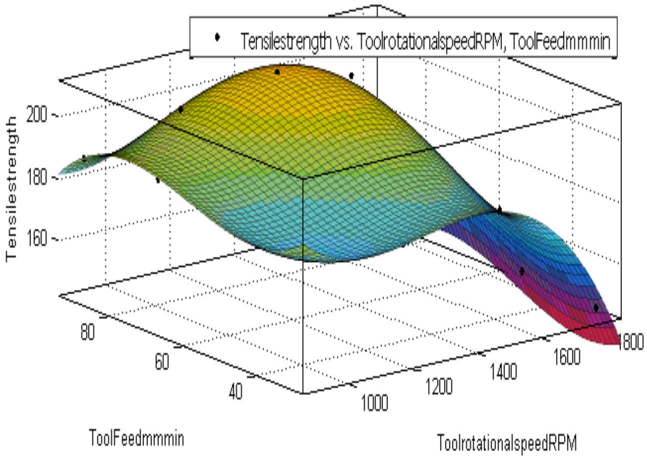
3.2 Hardness

The hardness profile obtained for the sample shown in the figure. The hardness test performs on the hardness tester with 16 diodes for the aluminium plate. To indicate the point on the HAZ, TMAZ, and weld nugget to obtain the hardness value on the weld joint. Hardness value was collected and stored in the table.

Table 4 Results of the twin stir technology

Sr no	Tool Rotational Speed (RPM)	Tool Feed (mm/Min)	Tensile strength (MPa)	Hardness (HRB)
1	1800	30	145.19	46
2	1800	70	160.77	47
3	1500	30	183.77	45
4	1200	50	189.27	48
5	900	90	186.40	47
6	1200	30	180.35	46
7	900	70	189.44	48
8	900	30	183.02	46
9	1500	50	184.69	48
10	1800	90	151.63	45
11	1500	90	199.34	45
12	1500	70	208.00	47
13	1800	50	147.29	48
14	1200	90	194.77	46
15	1200	70	197.00	47
16	900	50	184.94	49

The above result can give information about the tensile strength and hardness value and input parameters are tool feed and tool speed. The given below graphs gives a representation of the tool speed vs tool feed with regards to hardness and tensile strength. This is to inform that tensile strength increase at 1500 rpm and feed is 50 to 70 at that time tensile strength increased. Other side hardness value decreased in 1500 rpm and 50 to 70 mm/min feed.



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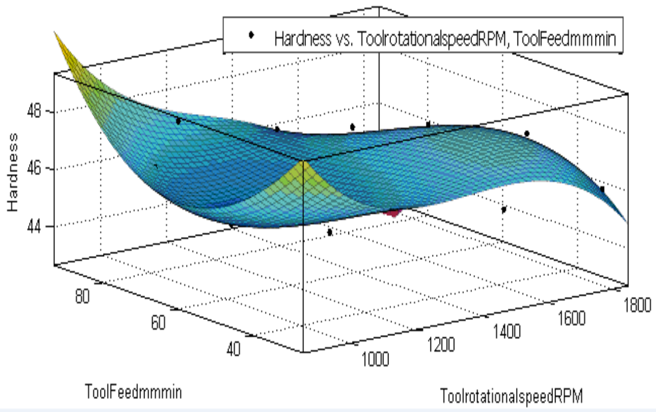

Figure 5 (I) tensile strength vs. Tool feed vs. tool rotational speed (II) Hardness vs. tool feed vs. Tool speed

IV. REGRESSION

Development of the regression model

Regression is a simple technique for founding the relationship between input data and output data of the process. Regression equations were developed using the mat lab 2012a analysis with the data available in the experimental data table. The model can be developed and work between the minimum and maximum value of the input and output parameters. This model gives the relationship between the friction welding process parameters such as rotational speed (rpm), Tool feed (mm/min) also calculate the tensile strength (Mpa), Hardness (HRB) were expressed as regression equations

4.1 Regression Equation for Tensile Strength (MPa)

The regression equation model developed for the tensile strength from the multiple input parameters with a third-degree relationship given in equation (1). This equation was generated by the mat lab 2012a. It is observed that the generated model can obtain the values of the R- square and R adjusted are 0.9764 and 0.9409 respectively.

Linear model Poly33.

$$\mathbf{F(X, Y)} = \boldsymbol{p00 + p10 \times X + p01 \times Y + p20 \times X^2 + p11 \times X \times Y + p02 \times Y^2 + p30 \times X^3 + p21 \times X^2 \times Y + p12 \times X \times Y^2 + p03 \times Y^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where, X= tool rotational speed (rpm), Y= tool feed (mm/min)

Coefficients (with 95% confidence bounds):

p00 = p00 = 815.8 (505.2, 1126), p10 = -1.349 (-2.019, -0.6792), p01 =-7.167(-12.44, -1.896), p20 = 0.001069 (0.0005729, 0.001565), p11 =0.003313(-0.0002398, 0.006866), p02=0.09963 (0.02254, 0.1767), p30 =-2.811e-07(-4.023e-07, -1.599e-07), p21 =-1.022e-06(-2.113e-06, 6.936e-08), p12 = -3.598e-06(-1.997e-05, 1.277e-05), p03 =-0.0005586 (-0.0009678, -0.0001494)

4.2 Regression Equation for Hardness:

The regression model generated for the hardness of the welding joint from the different multiple linear regression model given in equation (2). This equation was directly generated in the mat lab 2012a from the third-degree relationship with the input parameters with the poly linear equation in the mat-lab. Also, this model has observed that a good prediction can get an R-sq value is 0.9247 with better predictions that can be obtained from the equation.

Linear model Poly33:

$$\mathbf{F(X, Y)} = \boldsymbol{p00 + p10 \times X + p01 \times Y + p20 \times X^2 + p11 \times X \times Y + p02 \times Y^2 + p30 \times X^3 + p21 \times X^2 \times Y + p12 \times X \times Y^2 + p03 \times Y^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

where, x= tool rotational speed (rpm), y= tool feed (mm/min)

Coefficients (with 95% confidence bounds):

p00 = p00 = 122.7(37.5, 207.9), p10 = -0.1437(-0.3274, 0.04004), p01 =-0.8673(-2.313, 0.5784), p20 = 9.556e-05(-4.046e-05, 0.0002316), p11 = 0.0007658 (-0.0002085, 0.00174), p02 =0.005812(-0.01533, 0.02695), p30 =-2.315e-08(-5.64e-08, 1.01e-08), p21 =-4.167e-08(-3.409e-07, 2.576e-07), p12 =-6.042e-06(-1.053e-05, -1.553e-06), p03 =1.563e-05(-9.659e-05, 0.0001278)

V. GENETIC ALGORITHM

The genetic algorithm mimics the principles of multi-objective optimization for obtaining the best solutions for complicated problems. The genetic algorithm process is explained below;

1. To select for representing the most influencing friction welding parameters as rotational speed (rpm) and feed (mm/min).
2. Select the parameters like population size, selection operators, cross over operator, mutation probability and fitness parameters with the preferred limit.
3. In this process generating the process parameters required population size within the defined limit.
4. Generate the tensile and hardness regression equation in the software and put the defined equation in the genetic algorithm.
5. Also put the defined limits for upper and lower boundaries for the input parameters.
6. Lastly find the fitness function that has achieved the optimum value and record the maximum value get from the combined process parameters.
7. We can get the final value for the multi-objective values for the input process parameters.

5.1 Genetic Algorithm Parameters

Genetic algorithm parameters were selected by the trial and error method to use for the friction stir welding process such that best performance is achieved to predict the optimum value in best interaction between the input parameters.

The GA parameters are rank-order selection, cross over probability, mutation probability, cross over operator were selected as per the literature.

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In the selection process the selected parameters are selection operator – Rank order, Cross over operator- single point cross over, cross over probability- 0.8, mutation probability-0.01, Population size-12, fitness parameters- multi-objective function. In this optimization, we can use the upper and lower limits of the friction stir welding process parameters as per the given below in table 5.

Table 5 Limits of the input parameters

Sr no	Friction stir welding process parameters	Lower limit	Upper limit
1	Tool rotational speed (rpm) (X)	900	1800
2	Tool feed (mm/min) (Y)	30	90

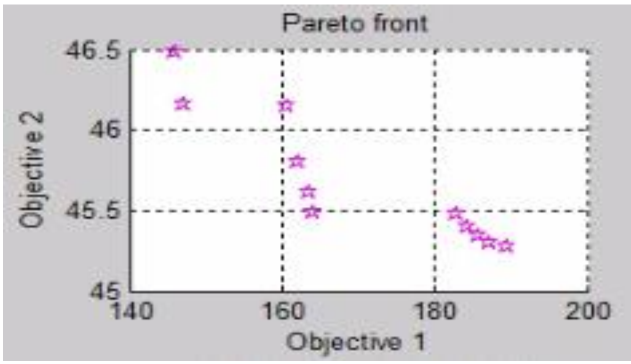
In this optimization the weight of the UTS and Hardness is given as the UTS (F1) + Hardness (F2) = 1 and the maximum value of the UTS (F1) are 198 and hardness (F2) is 45 and we use maximization problem we found in the table and it is useful for the optimization. In this process taken by the value of MIN is taken as 0.02 and MAX taken as the 0.08

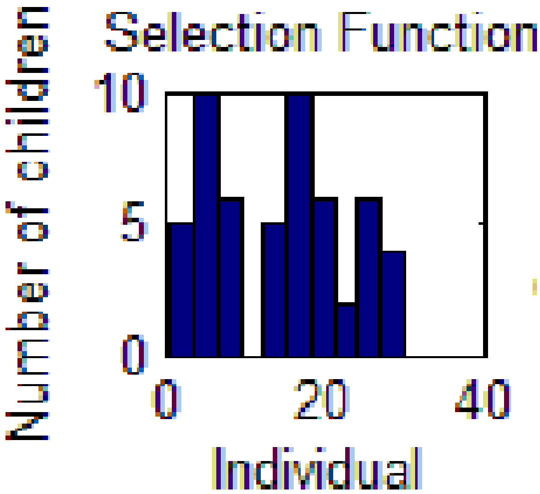
5.2 Results and discussion

In this work, the optimized value for the different weight of the UTS and Hardness has been shown in the given output table. As mentioned that earlier we obtained the solution of the algorithm stand the best amount of the value of the input and output process parameters. In the table given below, we can show the value interaction of the output parameters tensile strength and hardness. Also gives the output value after the first interaction in the optimization table 6 given below.

Table 6 Output value after the first interaction of the optimization.

Rank	Tool rotational speed rpm (X)	Tool Feed mm/min(Y)	Tensile strength MPa (F1)	Hardness HRB (F2)
1	1073.005	61.29174	189.4702	45.27461
2	1074.978	57.87821	187.2275	45.29928
3	1075.487	55.7298	185.7694	45.33927
4	1074.552	53.50837	184.2481	45.39874
5	1075.542	51.29468	182.8383	45.47664
6	1789.022	71.50772	163.998	45.48585
7	1789.058	70.28385	163.646	45.61216
8	1791.607	68.06993	162.1693	45.8024
9	1790.312	64.23993	160.6658	46.14801
10	1789.229	32.30342	146.9366	46.15299
11	1791.621	36.61531	146.0091	46.47805
12	1073.005	61.29174	189.4702	45.27461





(I) objective 1 vs objective2 (II) Individual vs the number of children

Figure 6 graphs (i)tensile vs. Hardness (ii) Individual vs the number of children

In the given first graph Objective 1 vs. objective 2 means tensile vs. Hardness in this graph we can easily analyze that two mechanical properties are opposite. When tensile increase that hardness decrease and hardness increase that time tensile increase. So that the friction stir welding process parameters found the influence of the tensile and hardness value for the friction stir welding of AA 7108. The other graphs give information on the individual vs. children gives the data of the number one has the highest children above the 10. After we get select the optimized process parameters for the confirmation of the practical value.

5.3 Validation

To the confirmation of the result obtained from the genetic algorithm the aluminium to be welded by the proper selection of the process parameters based on the selection. After optimization select only one process parameters for the combination. Friction stir welding had been done for the one sample for each combination and examine the tensile strength and hardness for the joint.

Table 7 comparing the result of the experimental and predicted value by GA

Specimen no	Tool rotational speed	Tool feed	Tensile strength (Predicted by GA)	Tensile strength (Experimental value)	Hardness (Predicted by GA)	Hardness (Experimental value)
1	1073.005 (1046)	61.29 (51)	189.47	186.03	45.27	47
Error			1.8%		3.8%	

The above table seeing that some of the deviation in the result from the predicted value by GA and experimental value. In this work, we have some limitation in the welding machine of the feed and speed so that we can get some variation in the value.

From the given above value, the variation in the optimized and experimental work have negligible up to 5% error but in this case, the tensile strength variation is 1.8% and hardness gives 3.8% so this is validate to the work.

VI. CONCLUSION

1. In this work, the FSW joint can be performed on the AA7108 with twin stir technology and used different input parameters.
2. After the weld joint performs testing on the tensile strength and hardness measure and optimized value with input parameters. This is two opposite objective can be easily obtained in the Genetic Algorithm.
3. To deal with the multi-objective optimization using the Genetic Algorithm and then after validating this work. The results indicate that the FSW process parameters obtain the maximum of the tensile and hardness.
4. Optimized process parameters (1046 rpm), Tool feed (61.29 mm/min), Tensile strength (189.47 Mpa) and hardness (45.27 HRB) It has been proved that the input process parameters with the genetic algorithm are easily fulfilling, and its practicability applicable.
5. This work can be used for further research on the manufacturing process in different materials and also change the distance between two tools.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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