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Optimization of Process Parameters for Friction Stir Welding of Aluminium Alloy and Alloy steel

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ABSTRACT: *Friction stir welding is a new solid - state joining process. In this experiment friction stir welding is carried out on aluminium alloy AA 5086 high strength structural alloy and alloy steel SS410 is a martensitic stainless steel that provides good corrosion resistance and high strength and hardness. The welding parameters like rotational speed, feed and offset were taken into consideration. EN19 was hexagonal tool pin profile was used in this study. The work has been carried out to study the tensile properties of the weldments like tensile strength. SEM analysis is used to study the microstructure of the weldments. Optimum parameters are found out using statistical software by varying the three parameters using Minitab software.*
Keywords: *Friction stir welding, EN 19, tensile strength, SEM and Microstructure*

I. INTRODUCTION

Friction stir welding (FSW) is a new welding process commonly known as a solid state welding process. This opens up whole new areas in welding technology. It is particularly appropriate for the welding of high strength alloys which are extensively used in the aircraft industry. FSW is considered to be the most significant development in metal joining in a decade and is a green technology due to its energy efficiency, environment friendliness, and versatility. The working principle of Friction Stir Welding process is shown in Fig. 1. A welding tool comprised of a shank, shoulder, and pin is fixed in a milling machine chuck and is rotated about its longitudinal axis. The work piece, with square mating edges, is fixed to a rigid backing plate, and a clamp or anvil prevents the work piece from spreading or lifting during welding. The half-plate where the direction of rotation is the same as that of welding is called the advancing side, with the other side designated as being the retreating side. The rotating welding tool is slowly plunged into the work piece until the shoulder of the welding tool forcibly contacts the upper surface of the material. The welding tool is then retracted, generally while the spindle continues to turn. After the tool is retracted, the pin of the welding tool leaves a hole in the work piece at the end of the weld. These welds require low energy input and are without the use of filler materials and distortion.

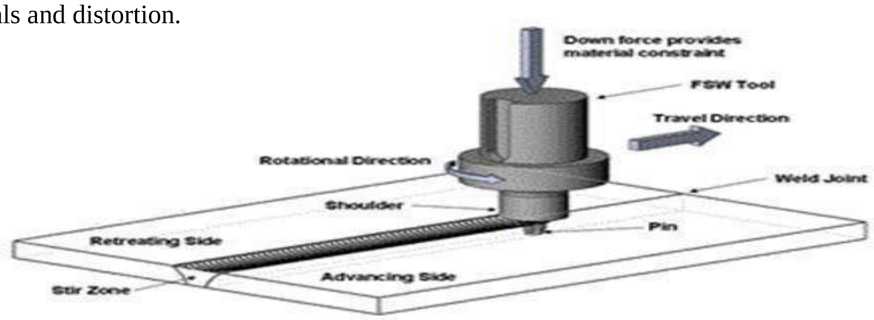


Figure 1 Schematic diagram of FSW Process

II.LITERATURE REVIEW

Takehiko Watanabe et.al.[1]: performed experiments on joining of aluminium alloy to a mild steel by friction stir welding and investigated the effects of pin rotation speed, the position for the pin axis to be inserted on the tensile strength and the microstructure of the joint.

T.J.Lienert et.al.[2]**:** experimented the friction stir welding of mild steel and calculated the process results , micro structures and mechanical properties .

M.S.Srinivas Rao et.al.[3]: studied the weld characteristics of aluminium alloy and found out of the tensile properties of the weldments like tensile strength, hardness and measurements of temperatures at various distances along the weld zone on the weldments.

M.Dehgani et.al.[4]: experimental study were performed of joints aluminium and mild steel and effects of various FSW parameters such as tool traverse speed, plunge depth, tilt angle , tunnel formation and tensile strength of joints were investigated.

Manish P.Meshram et.al.[5]: performed experimental study on stainless steel with varying parameters like tool rotation speed and welding speed. Optical microscopy is used to see the microstructure and followed by tensile tests.

Xun Liu et.al.[6]: conducted experiment on dissimilar aluminium alloy and advanced high strength steel with three process parameter like tool rotation speed, welding speed and tool offset. Tensile tests and Scanning Electron Microscopy (SEM) were carried out on the welded joints.

Chen Thaiping et.al.[7]**:**studied the welds of aluminium alloy and low carbon steel using low traverse speed and rotation speed which are significant process parameters, yield a higher C-notch Charpy impact value.

III. EXPERIMENTAL WORK

Friction stir welding (FSW) is performed on Aluminium Alloy (Al 5086) and Stainless Steel (SS 410) of dimension (150mm X 75mm X 4mm) and their chemical composition is checked before experimentation,

Table 1: Aluminium Alloy 5086 chemical composition

Al %	Mg%	Cr%	Mn%
95.4	4	0.15	0.4

Table 2: Stainless Steel 410 chemical composition

C%	Mg%	P%	S%	Si%	Cr%
0.1	1	0.040	0.030	1	11.5-13.5

The experimental work was carried out in 3 phases. In the first phase the process parameters and their levels were found out. This is done by examining various literature reviews and then the experiments were planned using the Taguchi method.

Before going further in our discussion it is important to know what Taguchi methods are. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr.Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly. The Taguchi arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. The arrays are selected by the number of parameters (variables) and the number of levels (states). This is further explained later in this article. Analysis of the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic. The experiments designed using Taguchi techniques for the research is shown in table below.

Table 3: Taguchi designed Experiments

Speed	Feed	Offset
710	20	0
710	25	0.1
710	30	0.2
900	20	0.1
900	25	0.2

900	30	0
1120	20	0.2
1120	25	0
1120	30	0.1

The parameters speed, feed, offset each were taken at three levels and the appropriate orthogonal array for three parameters at three levels is an L9 orthogonal array shown in above table. Second phase of the experiment is to perform welding according to above designed table of experiments, initially the Aluminium Alloy (Al 5086) and Stainless Steel (SS 410) sheets purchased were cut into pieces each of dimension (150mm X 75mm X 4mm) using a shear cutting machine. In the final phase the welded pieces are subjected to tensile tests on a universal testing machine to evaluate the strength of welded joints and the results were noted down as shown in the table The welded pieces are cut according to ASTM E8M-04 standard code on a Wire EDM cutting machine.

Table 4: Analysis Data

Speed	Feed	Offset	UTS
710	20	0	181.5
710	25	0.1	138.5
710	30	0.2	203.2
900	20	0.1	145.45
900	25	0.2	173.75
900	30	0	138.1
1120	20	0.2	165.7
1120	25	0	161.9
1120	30	0.1	176.9

IV. RESULTS

Mean and Signal to Noise ratio

The Mean and signal to noise ratio are the two effects which influence the response of the factors. The influencing level of each selected welding parameter can be identified. The tensile strength of the FSW weld is taken as the output characteristic. The response table for the S/N ratio shows that the offset ranks first in the contribution of good joint strength, while speed and feed take the second and third ranks. The same trend has been observed in the response table of the mean which is presented in Tables 5 and 6 respectively. The responses for the plot of the S/N ratio and Mean are shown in Fig.2. The tensile strength is estimated to be the maximum at 710 rpm rotation speed, offset 0.2 and 30 mm/min travel feed; which is optimal from the plots obtained.

Table 5: Response Table for Signal to Noise Ratios

Level	Speed	Feed	Offset
1	44.72	44.27	44.06
2	43.62	43.94	43.68
3	44.10	44.64	45.11
Delta	1.10	0.70	1.44
Rank	2	3	1

Table 6: Response Table for Mean

Level	Speed	Feed	Offset
1	174.4	164.2	160.5
2	152.4	158.0	153.6
3	168.2	172.7	180.9
Delta	22.0	14.7	27.3
Rank	2	3	1

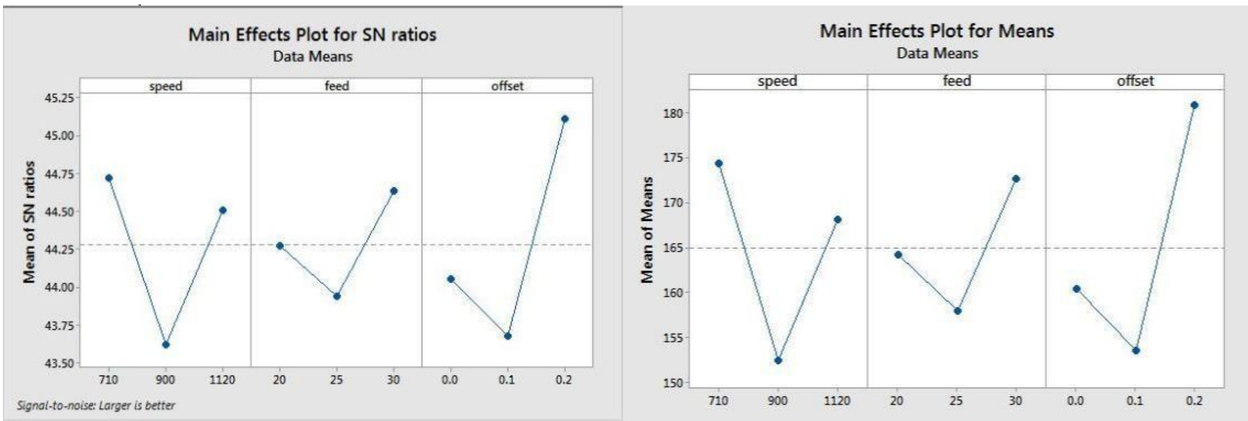


Figure 2: Main effects Plot for S/N Ratios and Means

Table 6: ANOVA Table

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Model	6	3570.82	595.14	6.04	0.149	
Linear	3	1620.58	540.19	5.48	0.158	
speed	1	1058.02	1058.02	10.74	0.082	19.60
feed	1	650.43	650.43	6.60	0.124	12.05
offset	1	9.66	9.66	0.10	0.784	0.179
2-Way Interactions	3	2796.52	932.17	9.46	0.097	
speed*feed	1	450.49	450.49	4.57	0.166	8.436
speed*offset	1	672.22	672.22	6.82	0.121	12.45
feed*offset	1	2556.54	2556.54	25.95	0.036	47.36
Error	2	197.00	98.50			
Total	8	5397.36				100

Analysis of Variance

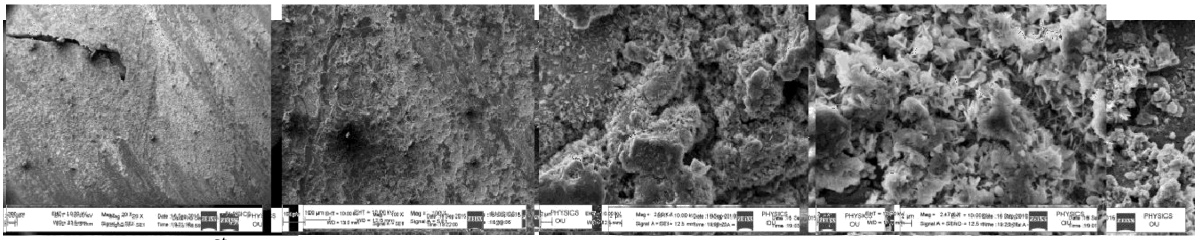
ANOVA is done using MINITAB software. The main aim of the analysis is to estimate the percentage of the individual contribution of the welding parameter on the tensile strength of the weld. The analysis showed that the two way interaction of Feed*Offset was the significant contributor with 47.36 followed by linear terms speed wit h 19.60 and two way interaction of speed*offset 12.45 respectively. This is shown in the table above.

SEM Analysis

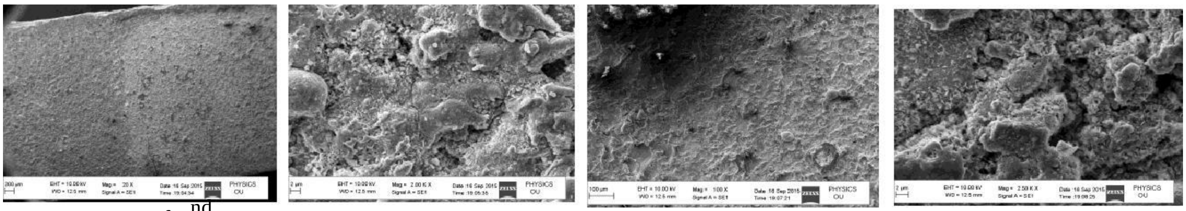
The microstructure analysis primarily is accomplished in two steps:

- Sample preparation
- Microscopic analysis

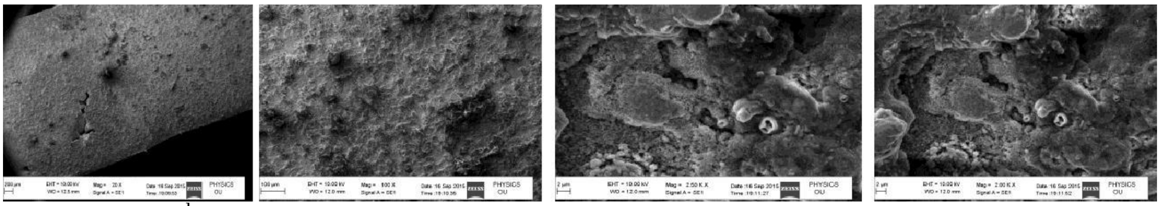
Figure 3 SEM specimens



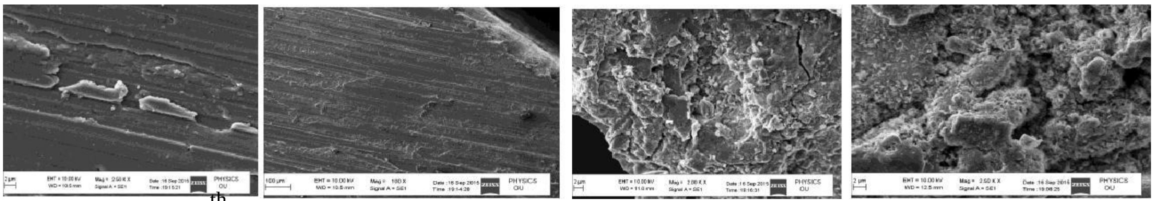
Microstructure of 1st experiment



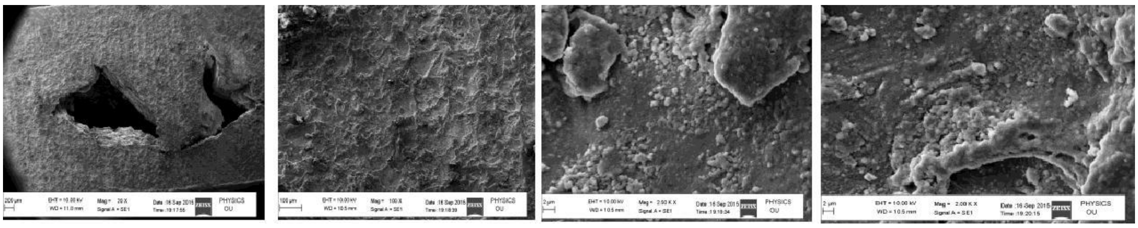
Microstructure of 2nd experiment



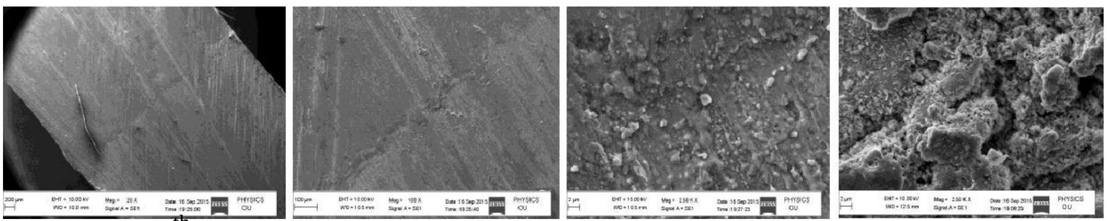
Microstructure of 3rd experiment



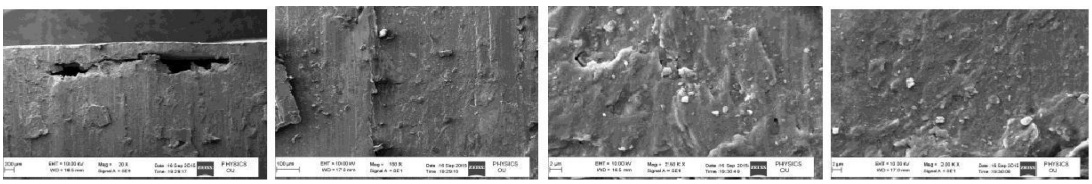
Microstructure of 4th experiment



Microstructure of 5th experiment

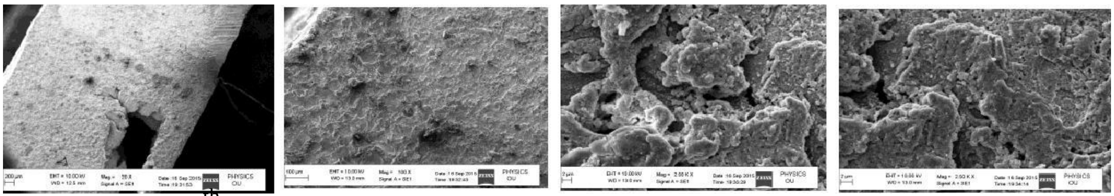


Microstructure of 6th experiment



Microstructure of 7th experiment

Microstructure of 8th experiment



Microstructure of 9th experiment

Aluminium Alloy AA5086 matrix and stainless steel SS410 microstructure is studied using SEM. Welding defects like tunnel defect and crack formation is obtained in experiment 4th , experiment 5th and experiment 9th due to insufficient heat generation of the tool, tool wear and the parameters which were defined using the design of experiments. In other experiments the microstructure is seen with no defects and also posses good tensile strength.

V. CONCLUSIONS

The friction stir welding was performed to join an aluminium alloy AA5086 and alloy steel SS410 using a hexagonal pinned tool which is made up of EN19 steel. The following results were obtained.

- Welds were produced by placing the aluminium alloy on the retreating side of the joint.
- The maximum tensile strength of the joint was obtained at the pin offset of 0.2 *mm* towards steel.
- Friction stir welding of aluminium alloy (AA5086) and stainless steel (SS410) was performed and the ANOVA showed that the two way interaction of feed*offset was the significant contributor with 47.36 followed by linear terms speed 19.60 and two way interaction of speed*offset is 12.45 respectively.
- The tensile strength is estimated to be the maximum at 710 rpm rotation speed, 0.2 mm offset and 30 mm/min travel feed; which is optimal from the plots obtained using the Minitab software.
- Microstructure analysis is also determined where some defects like tunnel defect and crack formation were seen in some welded joints.

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