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Joining of AA3102 aluminium alloy with carbon steel 1010 by FSSW process using optimized weld parameters

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Abstract: Friction Stir Spot Welding (FSSW) is a non-fusion welding process which creates a metallurgical bond between two specimens. Since Resistance Spot Welding (RSW) has many disadvantages including high wear rate of electrode and the welding of materials using this RSW technique generates high amount of heat in the specimen and it also cools rapidly, due to this rapid cooling the material becomes brittle at that welded area and thus reducing the physical properties of the material, due these effects FSSW has been selected to weld AA3102 and Carbon Steel 1010. FSSW is governed by three process parameters which include, Tool Rotational Speed, Dwell time, Load. In this work the effect of process parameters on joint strength has been studied based on experimental and numerical results. The Taguchi method is selected as a tool to identify the optimized process parameters for welding AA3102 and Carbon Steel 1010. The experiments conducted as a combination of the process parameters were made based on the result given by the Taguchi orthogonal table. The Taguchi method uses Signal to Noise ratio (S/N ratio) to determine the effective process parameter. The specimens that are welded using these parameters were tensile tested and with the help of the results obtained the Taguchi analysis is done and the parameters which will yield the maximum strength is obtained.

Keywords: Friction Stir Spot Welding (FSSW), Tool Rotational Speed, Dwell time, Load, Taguchi method.

I. INTRODUCTION

In order to meet the present demands, to reduce the weight of structures, machines and also to meet the required strength there is a need for using dissimilar materials. But joining of these dissimilar materials is a tedious process and several researches have been carried out to weld various dissimilar materials according to their applications. Friction Stir Spot Welding (FSSW) is a solid state welding process which operates below the melting point of the work piece. The individual spot welds are created by pressing a rotational tool with a high force on to the surface of the work piece. Resistance Spot Welding (RSW) is a very commonly used technique in many of the automotive industries to join the dissimilar materials. But this RSW technique has many limitations which include high wear rate of electrode, high temperature and rapid cooling rate causes the formation of brittle microstructure. In order to avoid these limitations FSSW technique is selected as an alternative approach to weld the aluminium alloy and the carbon steel. FSSW process also has many advantages which include low distortion, excellent mechanical properties and is more economical than RSW process. Aluminium 3102 which is an alloy in the wrought aluminium- manganese family. It has good strength, good workability and high corrosion resistance. The chemical composition of these materials has been given in Table.1.

In the year 2001, Friction Stir Spot welding was developed as a substitute for Resistance Spot Welding in automotive sectors to weld aluminium sheets. In the last 10 years the feasibility of the joining aluminium and steel has been moderately studied. The first published study was by Uzen et al and it was mainly focussed on joining AA6013 to-T4 to X5CrNi18-10 stainless steel. Although the fatigue testing showed a 30% reduction in results compared to the ones with AA6013 as base metal, no tensile testing results were provided. In FSSW mainly three process parameters were considered which include tool rotational speed, load and dwell time. The experiment is carried out by varying one parameter at a time and keeping the other parameters constant. This conventional step by step process involves large number of test runs. To avoid these disadvantages the use of design of experiments (DoE) mainly based on Taguchi approach is the most efficient technique to reach the conclusion with minimum number of trials. The tool material was selected as tungsten carbide since it has high hardness and strength. From the literature survey done pin profile was selected as taper cylindrical since it has a good impact on welding of these dissimilar materials. The material with low melting point (aluminium) is kept at top and the material with high melting point (carbon steel) is kept at bottom.

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The experiment is carried out by implementing the appropriate process parameters as given by the Taguchi approach and the specimen is tensile tested to check the strength of the welded specimen.

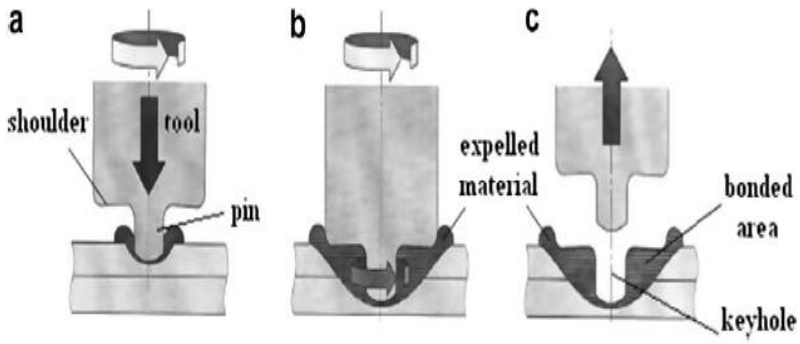

Fig 1. Three phases of Friction Stir Spot Welding process (a) Plunging, (b) Stirring and (c) Retracting [4]

Table.1.1. Chemical composition of Aluminium 3102.

Material	Al	Cu	Fe	Mn	Si	Zn	Ti
Aluminium 3102	97.85 – 99.95%	0.1%	0.7%	0.05 – 0.40%	0.4%	0.3%	0.1%

Table.1.2. Chemical composition of Carbon steel 1010.

Material	Fe	Mn	C	Ph	S
Carbon Steel 1010	99.18-99.62%	0.30-0.60%	0.08-0.13%	0.04%	0.05%

II. EXPERIMENTAL PROCEDURE

In this study, 3mm thick plates of Aluminium 3102 and Carbon steel 1010 of dimension 100 mm X 30 mm is taken. This experiment is carried out using a Friction Stir Welding machine. The tool material was selected as tungsten carbide with dimensions of 16mm shoulder diameter and the geometry of the pin was selected as taper cylindrical. The length of the taper cylindrical pin was fixed as 5mm and the root diameter of the pin was fixed as 5.5mm and the tip diameter of the pin as 4.5mm with a taper angle of 11.42°. The tool shoulder was made with 2 degree concavity in order to avoid the excess flow of material outside the tool when the tool plunges into the specimen.

The rotating tool is plunged into the work piece with a constant plunge rate with a required load. The stirring phase of FSSW is started with the completion of tool plunging. In this phase the tool is rotated without plunging. The duration of this phase is called dwell time. Upon reaching the determined dwell time the rotation of the tool was immediately stopped. Several experiments were carried out by changing the parameters and the welded samples are tensile tested to know the strength of the welded specimen. Fig.3. shows the samples that are welded using different process parameters. The welding parameters and the experiments carried out using different parameters were given in Table.2. and Table.3.

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Fig.2. Friction Stir Welding machine at Coimbatore Institute of Technology

Fig.3.Welded specimens

Table.2. Welding parameters

Symbol	Welding parameters	Unit	Level 1	Level 2	Level 3
A	Dwell time	s	3	7	10
B	Load	kg/cm^2	10	17	20
C	Tool rotational speed	rpm	750	800	850

Table.3. Ultimate Tensile Strength of the welded specimens.

Trial Run number	Welding parameters			Ultimate tensile strength (N/mm^2)
	A Dwell time (s)	B Load (kg/cm^2)	C Tool rotational speed (rpm)	
1.	3	10	750	29.5
2.	3	17	800	29
3.	3	20	850	28.5
4.	7	10	800	35
5.	7	17	850	33
6.	7	20	750	32.5
7.	10	10	850	31
8.	10	17	750	30
9.	10	20	800	28

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III. EXPERIMENTAL DESIGN

The Ultimate Tensile Strength(UTS) of designed experiments are shown in Table.4. The Taguchi method uses Signal to Noise(S/N) ratio. The Table.4. shows the calculated S/N ratio of the experiments. The term "Signal" represents the desirable value for the output characteristics and the term "Noise" the undesirable value for the output characteristics. Therefore S/N ratio is the ratio of mean to square deviation. This Taguchi approach uses the S/N ratio to measure the quality characteristic deviation from the desired value.

The S/N ratio is defined as,

$$\eta = -10 \log(MSD) \quad (1)$$

where MSD, is the Mean Square Deviation for the output characteristic.

The Mean Square Deviation is given by the equation,

$$MSD = 1/n \sum (1/T_i^2) \quad (2)$$

where n is the number of test and T_i represents the ultimate tensile strength of the i^{th} test. The last column of Table.3. represents the value of the ultimate tensile strength and the corresponding S/N ratio were calculated using Eqs (1) and (2).

Table.4. Calculated S/N ratio

Trial Run Number	Calculated S/N ratio
1.	29.39
2.	29.24
3.	29.09
4.	30.88
5.	30.37
6.	30.23
7.	29.82
8.	29.54
9.	28.94

Since the design has a repetable parameters then it is possible to separate the effect of each welding parameters at different levels. For example the the mean S/N ratio for Dwell time at level 1, 2 and 3 can be calculated by averaging S/N ratio for the experiments 1-3, 4-6, 7-9 respectively. The Table.5. shows the mean S/N ratios for each level of welding parameters. The total mean ratio for nine experiments were calculated as 29.72 dB. The S/N response graph for weld strength was drawn using the results given in Table.5. Graphs are plotted with mean S/N ratio on y-axis and the process parameters including dwell time, tool rotational speed and load on the x-axis. The points plotted are joined with a straight line. It should be noted that the point with higher mean S/N ratio better is the weld quality. The parameters with low S/N ratio will have poor weld strength. From the three graphs obtained as a result of mean S/N ratio, the value with higher S/N ratio is selected in each graphs respectively. These values obtained from each graphs will result in better weld with high mechanical strength.

IV. RESULTS

Fig.3. shows the apperance of the test specimen after joining. As shown in the above given figure the specimen is welded without any defects. The shape of the tool is transferred onto the joint in which the tool is pressed into the specimen which generates a ring of excess metal around the weld. The parameters that are mentioned are taken from the literature survey that is done. The parameters are analysed and the specimens that are welded using these parameters are tensile tested and it is checked for its mechanical strength. The process parameters such as dwell time, tool rotational speed and load determines the joint properties of the friction stir spot welds. The heat input and processing temperature

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can be controlled by adjusting the tool rotational speed and dwell time. The consolidation between top and bottom of the plates during friction stir spot welding can be controlled by the load given. Increasing the tool rotational speed results in more extensive stirring and formation of wider stir zone during friction stir spot welding, however too high tool rotational speed also lowers the mechanical properties due to high heat input. With the help of the parameter levels obtained by taguchi method and the result of the tensile test which are mentioned in Table.3., S/N ratio was calculated to determine the optimal process parameters for better weld. The calculated S/N ratio is mentioned in Table.4. The analysis report is generated and the mean S/N ratio is calculated and they are plotted against the different process parameters. Table.5. shows the mean S/N ratio that is calculated for each process parameters.

Fig.4.1, 4.2, 4.3 shows the plotted graph between the mean S/N ratio that is obtained for each process parameters. The comparision between the experimental observations and the numerical predictions, the tensile test of weld samples indicate that mechanical properties of weld joints are dependent on the welding parameters.

These process parameters play a major role in obtaining weld joint with mechanical properties very close to the base metal. From the graph it is identified that, for the given load the mean S/N ratio decreases with increase in the load given which shows that the load with 10 kg/cm^2 is better and in tool rotational speed the mean S/N ratio decreases upto certain level and it again increases which shows that a tool rotational speed of 850 rpm is better and in considering the dwell time, the mean S/N ratio increases upto certain limit and it decreases after a specific period, which shows the dwell time of 7s is better for a proper weld of Aluminium 3102 and Carbon steel 1010. The dashed line at the center of the graph represents the total mean S/N ratio (29.72 dB) of the experiments.

Table.5. Mean S/N ratio of weld parameters.

Welding parameters	Mean S/N ratio				
	Level 1	**Level 2**	**Level 3**	**Max-Min**	**Rank**
Dwell time	29.00	33.50	29.67	4.80	1
Load	31.83	30.67	29.67	2.17	2
Tool rotational speed	30.67	30.67	30.83	0.17	3

The main effect plot for SN ratios (Data Means):

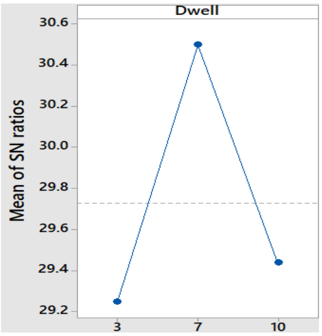

Fig.4.1. Mean of SN ratios vs Dwell

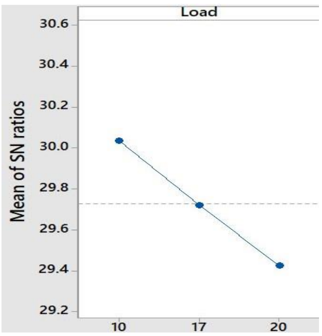

Fig.4.2.Mean of SN ratios vs Load

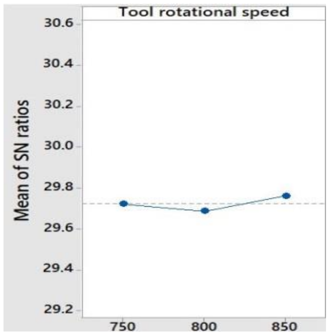

Fig.4.3.Mean of SN ratio vs Tool rotational speed

V. CONCLUSION

The effect of friction stir spot welding parameters of Aluminium 3102 and Carbon steel 1010 weld strength was evaluated with the help of Taguchi method. The following results were obtained from the experimental and analytic methods.

- The larger number of parameters affecting the mechanical properties of welded joints requires a proper planning characterization tests, this reduces time and cost.
- The dwell time, the tool rotational speed, load were effective on joint strength of Aluminium 3102 and Carbon steel 1010 by FSSW process

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- The dwell time was the most dominating process parameter.
- The optimum welding parameters for good weld strength are determined as dwell time 7s, load 10 kgf/cm^2 and the tool rotational speed as 850 rpm.

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