Application Of Taguchi Technique For Friction Stir Welding Of Aluminum Alloy AA6061

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Abstract.

Friction Stir Welding is a solid state joining technique which is widely being used for aerospace, marine, automotive and other applications for joining similar and dissimilar metals. Compared to other welding techniques FSW produces better mechanical properties in the weld zone. The main objective of this article is to find the optimum tool material for joining of a butt joint aluminium alloy AA6061. Three major factors at three levels namely tool material, rotational speed and axial force are considered for the present study. The uncontrollable factors include ultimate tensile strength, percentage of elongation and hardness which can be converted to signal-to-noise ratios, by using Taguchi method which is a multiple response process used to optimize the factors. Further a three-dimensional model has been developed using SolidWorks 2010 and by using ANSYS 13.0 Workbench, static structural analysis is done. The equivalent stress values for different combinations are noted from the response table and we get the optimum rank for the process parameters. Hence the prediction of the optimum process parameters using Taguchi technique is investigated.

Keywords. Friction Stir Welding, Design of experiments, Taguchi method, Aluminium AA6061, means, S/N ratio.

1. Introduction.

Friction Stir Welding is a novel material joining technique invented by Thomas et al. The welding institute, TWI in 1991 [1]. Material subjected to FSW does not melt and recast and hence the resultant offers advantage over conventional arc weldments, such as better mechanical properties at weld zone and fewer weld defects. In recent years FSW has become one of the most important solid state joining process, and it consumes considerably less energy.

Particularly given the design and manufacturing benefits they afford over established mechanical joining methods. Whilst a variety of welding methods have been identified for airframe structures, friction stir welding is an important candidate technique that is distinctive in being a low energy, solid-state process [2]. Friction Stir Welding is a hot-shear joining process in which a non-consumable, rotating tool plunges into a rigidly clamped work piece and moves along the joint to be welded [3].The rotating tool is a cylindrical shape which consists of a shoulder and a pin, the profiled pin may be threaded or unthreaded while the length less than the weld depth which extrudes from the shoulder. The FSW process begins by plunging the tool into the joint until the shoulder contacts the surface of the work piece. Heat is generated by the rubbing action of tool shoulder as the tool translates along the joint. Shoulder is responsible for the generation of heat and for containing the plasticized material in the weld zone, while pin mixes the material of the components to be welded, thus creating a joint.

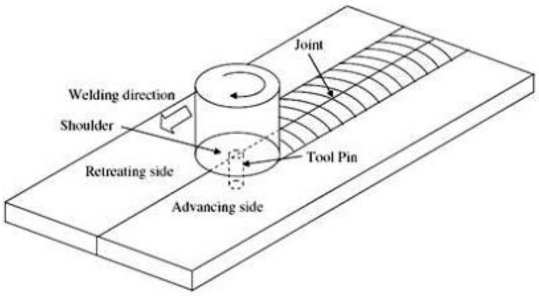

Fig 1 Friction Stir Welding Process

2. Design of Experiments.

Design of experiments (DOE) or **Experimental design** is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. A methodology for designing experiments was proposed by **Ronald A. Fisher.**

Design of experiments is a sequence of tests in which changes are made to the input variables of a system. and the effects on response variables are measured [4]. Design of experiments is applicable to both physical processes and computer simulation models. However in statistics these terms are usually used for controlled experiments. Experimental design is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data to be collected. Factorial experimental designs investigate the effects of many different factors by varying them simultaneously instead of changing only one factor at a time. Factorial designs allow estimation of the sensitivity to each factor and also to the combined effect of two or more factors.

The fundamental principles in design of experiments are solutions to the problems in experimentation posed by the two types of nuisance factors and serve to improve the efficiency of experiments. Those fundamental [4]. principles are

- Randomization
- Replication
- Blocking
- Orthogonality
- Factorial experimentation

Uses.

The main uses of design of experiments are

- Discovering interactions among factors
- Screening many factors
- Establishing and maintaining quality control
- Optimizing a process, including evolutionary operations (EVOP)
- Designing robust products

3. Taguchi method.

Taguchi methods are statistical methods developed by **Genichi Taguchi** it is one of the most powerful DOE methods for analyzing of experiments. It can be used to improve the quality of manufactured goods, and more recently also applied to [5]engineering biotechnology, marketing and advertising. Taguchi first applied his methods was Toyota. Since the late 1970s.

Product robustness, pioneered by Taguchi, uses experimental design to study the response surfaces associated with both the product means and variances to choose appropriate factor settings so that variance and bias are both small simultaneously. Designing a robust product means learning how to make the response variable insensitive to uncontrollable manufacturing process variability or to the use conditions of the product by the customer.

Taguchi defines three quality characteristics in terms of signal to noise (S/N) ratio which can be formulated for different categories which are as follows [6]:

3.1 Nominal and small are best characteristics.

Data sequence for stresses developed on FSW tool, which are lower-the-better performance characteristics, are pre processed as per equations.

$S/N = -10 \log (\hat{y}/s^2 y)$…………………1

$S/N = -10 \log ((l/n)(\Sigma y^2))$…………….2

3.2 Larger is best characteristics.

Data sequence for material removal rate, which is higher-the-better performance characteristics, is pre processed as per equation 3.

$S/N = -10 \log ((1/n)(\Sigma (1/y^2)))$……...3

where, y is value of response variables and n is the number of observations in the experiments.

4. Taguchi method- based design of experiments.

This involved the following steps [7].

1. Definition of the problem
2. .Identification of noise factors
3. Selection of response variables
4. Selection of process parameters and their levels
5. Selection of the orthogonal array
6. Material Data
7. Experimental procedure and set-ups
8. Results of the data and prediction of optimum level

4.1. Definition of the problem

A brief statement of the problem under investigation is “comparison of the performance of different types of FSW tool materials”

4.2. Identification of noise factors

The environment in which experiments are performed is the main external source of variation of performance of welding process. Some examples of the environmental noise factors are temperature, vibrations and human error in operating the process.

4.3. Selection of response variables

In any process, the response variables need to be chosen so that they provide useful information about the performance of the process under study.

4.4. Selection of process parameters and their levels

The process (welding) parameters affecting the characteristics of welded parts are: types of pin profiles, Tool rotation and traverse speeds, Tool tilt and plunge depth, Tool Design and Tool material.

4.4.1. Selection of Tool Traverse speed

Available literature on FSW indicates that the influence of welding speed on work piece and surface roughness changes with the welding speed.

Most of the researchers have reported improvement in surface roughness with an increase in welding speed. In this experiment we took the tool traverse as a constant, 1.5mm/sec

4.4.2. Selection of axial force on the tool

It is known that the axial force on the tool influences the work piece by forces acting along the tool. A downward force is necessary to maintain the position of the tool at or below the material surface. Some friction-stir welding machines operate under load control but in many cases the vertical position of the tool is preset and so the load will vary during welding. In our experiment we varied three types of axial forces along the tool.

4.4.3. Selection of Tool Rotational Speed

This is the rotational speed of the tool in rpm which acts the main role in the FSW process, and is responsible for the heat generation in the work piece and also stirs the metal from advancing to retreating side vice versa. In this experiment we took three parameters of speed in rpm.

4.5. Selection of orthogonal array

In Taguchi method-based design of experiments, to select an appropriate orthogonal array for experimentation, the total degrees of freedom (DOF) needs to be computed. The DOF is defined as the number of comparisons between machining parameters that need to be made to determine, which level is better and specifically how much better it is[8]. For example, a three-level machining parameter has two DOF. The DOF associated with interaction between two machining parameters are given by the product of the DOF for the two machining parameters. In the present study, interactions between the three machining parameters will be considered. Therefore, there are 18 DOF owing to three three-level independent parameters. In this study, a L_9 orthogonal array as shown in table 1, has been used because it has 8 DOF. It can accommodate nine three-level parameters and three interactions at most.

Table 1 The basic Taguchi L_9 (3^3) orthogonal array

Run	Control factors and levels		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.6.Material Data.

Table 2 Mechanical Properties of AA6061alloy

Young modulus (GPa)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation (%)	Toughness (J/mm3)
68.9	276	310	17	80.7

Table 3 Physical Properties of AA6061 alloy

Density	Hardness	Melting Range	Thermal Conductivity	Sp.heat
Kg/mm^3	BHN	˚C	W/m-k	J/Kg-˚C
68.9	107	582-652	167	0.896

Table 4 Chemical Composition of AA6061 alloy

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8-1.2	Max 0.15	0.4-0.8	Max 0.15	Max 0.25

Table 5 Friction Stir Welding parameters and their levels

FSW parameter / Variable parameters	Symbol	Level 1	Level 2	Level 3
Tool Material	A	HSS	SS	MS
Rotational Speed of Tool (rpm)	B	800	1000	1200
Axial Load of Tool (N)	C	1000	1200	1400

4.7. Experimental procedure and Set-up

After the orthogonal array has been selected, the second step in Taguchi parameter design is running the experiment.

The AA6061 Aluminium alloy was used in this

Order	Material type (A)	Rotational speed of tool	Axial Load of tool N	Tool Traverse	Equivalent Stress	S/N ratio db
1	HSS	800	1000	1.5	149.12	43.47
2	HSS	1000	1200	1.5	178.94	45.05
3	HSS	1200	1400	1.5	208.77	46.35
4	SS	800	1200	1.5	178.67	45.04
5	SS	1000	1400	1.5	208.45	46.38
6	SS	1200	1000	1.5	148.89	43.45
7	MS	800	1400	1.5	208.77	46.39
8	MS	1000	1000	1.5	149.12	43.47
9	MS	1200	1200	1.5	178.94	45.05

Table 6 Experimental values of equivalent stress (mean) and S/N ratio.

investigation. All the welds were performed in plates of 8mm thick in a butt welding arrangement with edge preparation.
Plates of 100mm x 50mm were welded along their long edge. The FSW equipment was used was a universal Milling machine available in the college Machines Lab. Here we took only the HSS tool for welding of dimensions 75mm of tool length and shoulder 63mm x Ø 8mm and pin 12mm x Ø3.

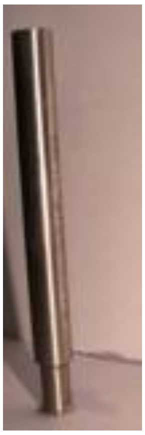

Fig 2 A FSW tool of HSS material used in the experiment

A model of the same dimensions above furnished is done in Solid Works 2010.Further in ANSYS 13.0 Work Bench the model is imported and nine Stress values are found as per the Table of orthogonal array, the values of A,B and C are changed accordingly and the respective Stress values are note down.

In Minitab under DOE, create Taguchi Design the basic Taguchi L_9 (3^3) orthogonal array the stress values are given by which are obtained from ANSYS Workbench. Then under analyze Taguchi

Design we get the Main effects plots for Means and

Signal to Noise ratio.

4.8. Results and Discussions

From the response table, from the means, we got the Rank as A2B3C1. Fig 2 depicts the variation of mean of Stress with respect of input process parameters such as Tool material, Rotational speed and axial load of tool. From the plot it is observed that the stress is increasing as the axial force is increasing. Whereas for rotational speed and tool material the stress value remained the same.

From the above table the mean and S/N ratios are obtained from software MINITAB 16.0[9]. In order to assess influence of factors on response, means and signal-to-noise (S/N) for each control factor are calculated. Signals are indicators of effect on average responses and noises are measures of deviations from experiment output. Appropriate S/N ratio must be chosen using previous understanding of the process [10]. In this study, S/N ratio was chosen according to criterion, larger-the-better, in order to maximize response. In Taguchi method, S/N ratio is used to determine deviation of quality characteristics from desired value.

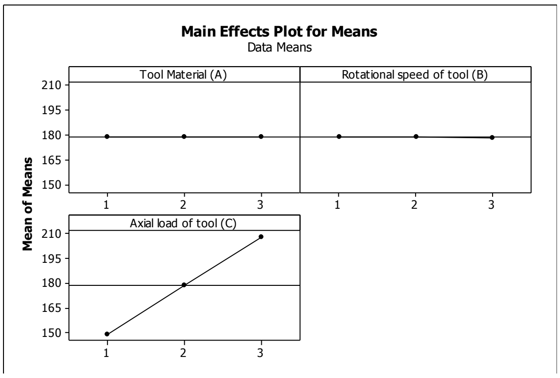

Fig 3 Main effects plots for mean of equivalent stress

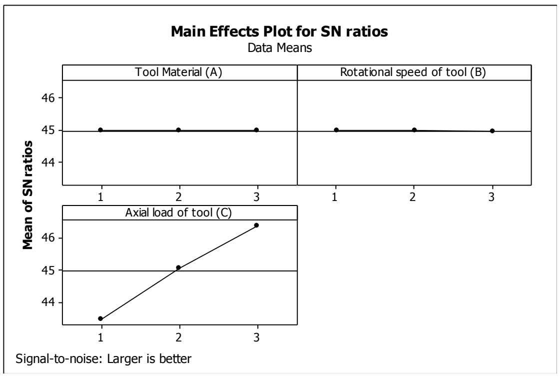

Fig 4 Main effects plots for SN ratios of equivalent stress

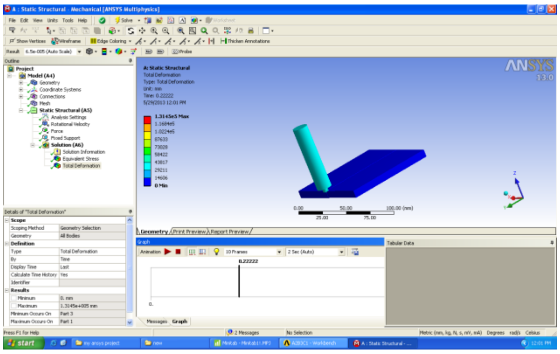

Fig 5 Structural analysis of tool in ANSYS 13.0 Workbench

The stress value from different random values of the three parameters viz. tool material, rotational speed and axial force were calculated from ANSYS 13.0 Workbench. And the Taguchi design is created in Minitab.

5. Conclusion.

The butt joining of Aluminum alloy AA6061 was successfully carried out using FSW technique. The samples were characterized by mechanical properties like equivalent stress. By using Taguchi design we analyze the stress values induced in the tool. The following conclusions were made from the present investigation.

- The optimum operating conditions of FSW have been obtained for two plates of aluminium alloy AA6061 welded in butt joint.
- From the experimental results the better performance is occurred at A2B3C1.
- A maximum equivalent stress of (208.77 Mpa) exhibited by tool with optimal process parameters (tool rotational speed, 1200 rpm; axial force, 1000N) as obtained from Taguchi method.
- Axial force is the dominant parameter for equivalent stress developed on the tool followed by rotational speed.
- The most significant FSW process parameter is axial force, which is consistent with the equivalent stresses in the tool.

6. Acknowledgements.

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