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AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF VARIATION OF TOOL GEOMETRY AND OPTIMIZATION OF PROCESS PARAMETERS ON FRICTION STIR WELDED ALUMINUM ALLOYS

Rama Narsu M[1], I Rani M[2]

[1]*AGM, MTAR Technologies Pvt Ltd.,ramanarsu@mtar.ac.in*[*]
[2] *Professor, MED, JNTUHCEH, marpuindira@gmail.com*
[*] *AGM, MTAR Technologies Pvt Ltd.Balanagar,Hyderabad – 37, 09492062062, ramanarsu@mtar.ac.in*

Abstract

Friction Stir Welding has many benefits when applied to welding of aluminum alloys and dissimilar materials which were difficult to weld. In order to prevent defective welded joints, utmost care should be taken during the selection of welding parameters. Tool pin diameter and taper of the pin, flute design which includes number, depth and taper angle and pitch of any thread form on the pin are the important parameters in addition to the tool rotational speed (TRS), weld speed (traverse speed/WS) and the axial force (F). The main parameter considered in the present work is variation of properties with the variation of tool geometry and tool rotational speed and weld speed. Experimental results obtained are analyzed. The joints are obtained by using various tool profiles with varied process parameters. An ANN model is developed using MATLAB and optimization of process parameters in carried out by comparing the results obtained by Design of Experiments (DOE) and experimental values. Using each tool, Friction Stir Welding is carried out at various parameters on different materials AA6061, AA6351 and AA6082.

***Keywords**:* Tool Rotational Speed; Weld Speed; Axial Force; DOE, Tool geometry.

1. INTRODUCTION

To join butt and lap joints, Friction Stir welding which is a solid state process is used. The FSW is a recent technique invented in 1991 by TWI (The welding Institute) and is being used to weld aluminium alloys of different series which were difficult to weld and were used less. Due to non- melting and re solidification of metal, distortion is low and the weld is free of porosity.

A non-consumable, rotating tool is brought in to contact with the plates to be joined as shown in the Figure.1. As the tool moves along the joining surface the heat is generated and below the solidus temperature [1, 7], the joints are formed. When the shoulder comes into contact with the surface of plates, the temperature increases due to heat generated and the pin of the shoulder stirs in the joining surface allowing flowing of the material backside of the pin. As the tool passes the metal cools and a processed zone is produced. A tool made of harder material than the plates to be joined is used. Earlier the aluminium alloys, zinc magnesium and other soft materials were joined using FSW. Presently the use of FSW process is extended to join materials with high temperatures, as the harder tools are being developed.

2.1 Stages of FSW Process

FSW cycle mainly consists of four stages namely Plunge Stage, Dwell Stage, Welding Stage and Pull out Stage. The stages which were followed in the FSW Process is as shown in Figure. 2.

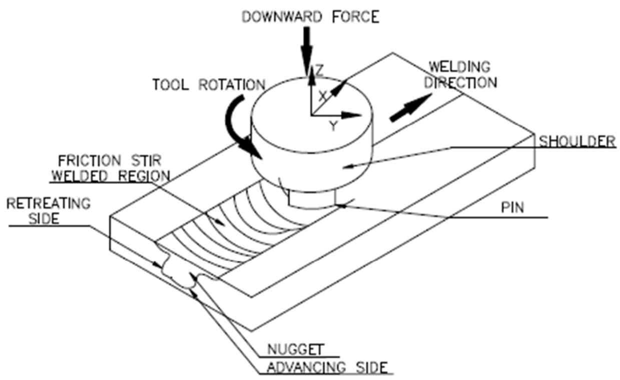

Fig. 1 Schematic diagram

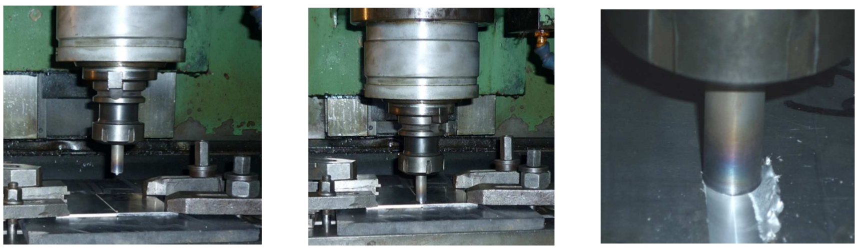

Fig. 2 Stages of friction stir welding experimental Process

2.2 Microstructure Features of Friction Stir Welds

The solid state nature of the FSW process produces microstructures with high characteristics. The first attempt at classifying micro structures was made by P L Threadgill (Bulletin, March 1997). The system divides the weld zone into distinct regions as unaffected material or parent material, Heat Affected Zone (HAZ), Thermo-Mechanically Affected Zone (TMAZ) and Weld Nugget as shown in Figure 3.

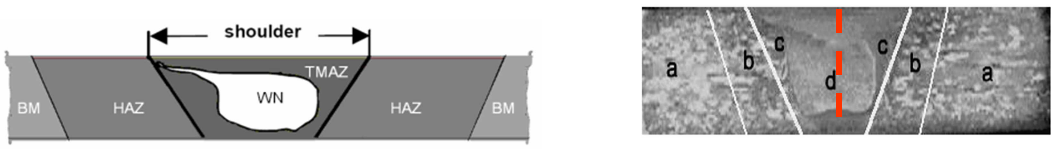

Fig 3 Different zones of FSW joint at the weld.

Although welding is a prominent joining process in terms of fabrication cost, the traditional arc welding methods are not capable of producing sound welds due to metallurgical problems in aluminium alloys. FSW process which was recently invented enables the welding of high performance aluminium alloys that are used in aircraft structures. In many industrial applications steels are replaced by nonferrous alloys, in most cases by aluminium alloys. Aluminium is an easily saved resource as it can be recycled. Pure aluminium is a silvery – white metal, light, non toxic, non magnetic and non-sparking. It can be easily machined and can be cast. The other major alloys of this series include AA6351, AA6005 and AA6082. By taking these various applications into consideration 6XXX series aluminium alloys are chosen as the base material. AA6061, AA6082 and AA6351 is used more in the fabrication of light weight structures where a high strength-to-weight ratio and good corrosion resistance is required.

FSW process requires a tool of harder material than the work piece material. When selecting a material for use as a FSW tool, design must be done with setting max loads on the tool, the high operating temperatures and the needed wear resistance. Loads on the tool can be many kilo Newtons (kN). Stress analysis should be performed to ensure proper design and undersized tools can fail at the time of operation. The failures could include the pin breaking and remaining back in the weld joint or the tool fracturing above its shoulder and being ejected from its holder. To reduce the likelihood of failure, the tool material must have high yield strength. The tool must also be able to withstand the required temperatures to heat the work piece material to a level just below its melting point. The properties of metals change with temperature and hence attention must be paid to both the yield strength and the operating temperature of the tool. An additional characteristic of concern is resistance to wear of tool. As the tool has to plastically deform another metal, it must be able to have a high resistance to wear. Most common materials used for tools are HCHC, H13 as they exhibit high yield strengths and toughness. They are used in processes where large loading, high temperature and frictional contact occur. The materials used for tools include easy availability and machinability, low cost and established material characteristics.

Based on the literature survey, the tool geometry is as per the thickness of the base plates. The diameter of the pin is equal to the thickness of the parts to be welded and its length is slightly shorter than the thickness of the part. Tool shoulder-to-pin diameter ratios play an important role in stir zone development [3]. Tools with shoulder-to-pin diameter ratios close to 1 (one) do not produce a TMAZ and do not adequately preheat and soften the material before the tool advances. Tools with very large shoulder-to-pin diameter ratios may preheat and soften too much the material, resulting in the material not sticking to the pin. The joints fabricated by the tools with shoulder-to-pin diameter ratios of (D/d) of 3 produced higher tensile strength and elongation [6] compared to that fabricated using the tools with D/d 2.5 and 3.5. The base plate chosen for this investigation is AA6061, AA6082 and AA6351. The other major function of the tool is to 'stir' and 'move' the material in the weld zone. The tool design is the important aspect for the uniformity of microstructure and properties. There is no path for free movement of the material when the shoulder comes into contact with the work piece.

The five profiles (cylindrical, tapered cylindrical, threaded cylindrical, square and triangular) which are considered for the tool pin are shown in Figure. 4 and the after heat treatment process the tools obtained which are used for the experimental work.

Fig.4. Straight cylindrical, Tapered, Threaded cylindrical, Square and Triangular profiled tools

3.0 DEVELOPMENT OF ANN:

Either from known or known source, a neural network may be trained with measured data. They are software tools designed to estimate relationships in data where they can be trained to perform classification, estimation, simulation and prediction of the underlying process generating the data. The Neural Networks package supports several function estimation techniques that may be described in terms of different types of neural networks and associated learning algorithms. Many research related to an applications of Artificial Intelligence (AI), especially Artificial Neural Networks (ANN) for engineering fields such as manufacturing processes prediction, monitoring and controlling are there. Thus, the new approach which ensures efficient and fast selection of the optimum conditions and processing of available technological data are the ANNs and is mostly used in the fields of biology, electronics, computer science, mathematics and engineering. The method has proved to be excellent for solving the optimization problems, for pattern recognition and for the adaptive control of machines. MATLAB platform is used for developing a Neural Network Model. ANNs are computational models, which replicate the function of a biological network, composed of neurons and are used to solve complex functions in various applications. Neural networks are a non linear mapping system that consists of simple processors, which are called neurons linked by weighted connections. An output is generated with each input neuron which is seen as the reflection that is stored in connections [2, 4]. The output signal of neuron is fed to the other neurons through inter connections as input signals. If the function is complex in nature, as the capability of single neuron is limited, many processing elements are connected. The performance of the network depends on activation function, network structure data representation and normalization of inputs and outputs.

The measured tensile strength results are used to train the networks. Network 1 is for square pin profile tool. The network created is a two layered feed forward network by considering TRS, WS and F inputs and number of hidden layer is one. Network 1 consists of two layers. Network transfer function is Tangent sigmoid function is the network transfer function and the neural network model is trained using Levenberg- Marquardt Algorithm. The experimental work is carried by varying the parameters and from the results obtained by conducting DOE and ANOVA it can be drawn that the mechanical properties obtained using square profiled tool are better when compared to other tools. An ANN model is developed for square profiled tool represented as network1. The network is trained using the experimental data with TRS, WS and F as inputs (Figure. 5) and tensile strength as output.

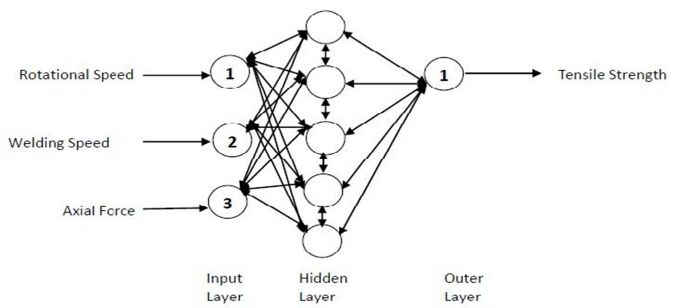

Fig. 5 Network 1& ANN architecture used

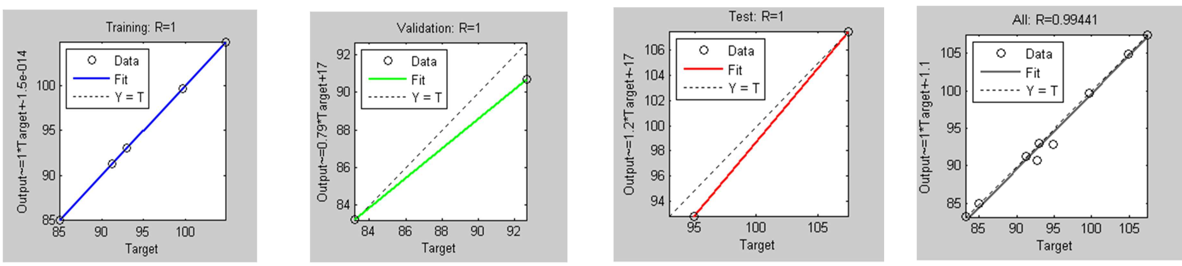

Fig 6: Training & Validation and Testing & Regression Graph of Network1

4. 0 RESULTS AND DISCUSSIONS:

In this chapter, the results obtained by varying the process parameters of FSW are analyzed and listed. Experiments for joining the aluminium alloys using friction stir welding were performed using DOE. Main effects based on ANOVA results for the responses of the joints are presented. The comparison of the experimental data with Artificial Neural Network data is presented. For both the profiles, comparison is made between tool rotational speed, axial force and welding speed with tensile strength. The results obtained for square profiled tool are as shown in Table 1, which include numerical values of experimental data and ANN data.

S.No	Axial Force, F kN	Tool Rotational Speed, TRS rpm	Welding Speed, WS mm/min	Experimental Tensile Strength MPa	Tensile Strength obtained from MATLAB MPa	Error
1	4	100	45	101.93	101.899	0.0031
2	5	1100	60	105.66	106.12	-0.46
3	6	1200	75	103.18	103.25	-0.0718
4	4	1000	45	103.18	101.18	2.01
5	5	1100	60	113.19	112.19	1.0293
6	6	1200	75	104.87	104.07	0.8
7	4	1000	45	107.49	107.36	0.13
8	5	1100	60	99.96	100.106	0.146
9	6	1200	75	101.28	101.3654	-0.0854

Table 1. Comparison of experimental values and predicted values of ANN Model

4.1 Comparison of Experimental Results and ANN Results:

As ANN of these parameters results a well-trained network, optimization and simulation of tensile strength can be possible in much complicated situations. A comparison is made between ANN data and experimental data with axial force, weld speed and tool rotational speed as parameters.

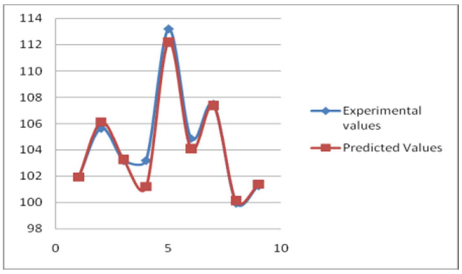

Fig. 7 Comparison of Experimental values and predicted values of Square Profiled

In the same way, comparison is made between ANN data and experimental data with tensile strength and welding speed as parameters. The fig. 6.8 presents the comparison between the ANN data and experimental data with the above parameters. With ANN the maximum tensile strength is obtained at 60 mm/min of the weld speed at 1000 rpm of tool rotational speed and axial force of 6kN. Similarly at 60mm/min, with experimental data the maximum tensile strength is achieved. In experimental data, maximum tensile strength is observed at 1000 rpm of tool rotational speed and 60 mm/min weld speed but better values are achieved than that of existing tool.

5.0 CONCLUSIONS:

Among the three base materials considered, AA6061 was found to exhibit better mechanical properties and this alloy is found to be amenable for friction stir welding by different tool profiles. H13 tool material is found to withstand for AA6061 without breakage of tip at the time of welding process. Increase in tool rotational speed causes more heat input and the tensile strength is low for increase in TRS as the TMAZ and HAZ is more. The Square profiled tool facilitates the stirring action from tip to the collar, and due to this the turbulence is avoided, when compared with the use of other tool profiles. The defect-free welds were possible with the square profiled tool for the same reason. The tool rotational speed of 1000 rpm, weld speed of 60mm/min and axial force of 6kN generated good welded joints (with maximum values of mechanical properties that were obtained) when Square profiled tool is used. From the results obtained it can be concluded that the shape of the tool pin and shoulder play a very important role in obtaining better mechanical properties for the weld joints. This is evident from the results obtained for the square pin profile due to flat faces

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produces a pulsating stirring action in the flowing material. A threaded cylindrical profile is also found to pulsating stirring action. This pulsating action leads to the development of smaller grains with uniformly distributed very fine structure and this, in turn, yielded higher strength and hardness. The values predicted using ANN are in good agreement with those obtained by experimental results. The percentage error between the predicted values and experimental values is observed to be minimal in the case of the existing tool. Hence it can be concluded that the ANN model can be applied with reasonable confidence to obtain the values of the mechanical properties for different combinations of the input parameters.

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