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Impact of Different Process Parameters on the Strength of Welded Joint in Friction Stir Welding

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Abstract: ***Friction stir welding process is used to combine high strength aluminum alloys, thermoplastic material and other metals also. In Friction stir welding high temperature results in excessive heat generation which ultimately results in various defects that leads to failure of the welded joint. Welded joints are defined on the basis of their strength which includes both types of strengths yield as well as tensile strength that termed as mechanical strength that shows how efficiently it will work, when heavy load is applied without any kind of rupture or failure. This paper presents the variation in the behavior of the welded joint while changing the different process parameters i.e. transverse or welding speed, rotation of spindle, axial force and pin profile of welding shoulder. Different experimental data is used to obtain the relationships between all process parameters and their effects on the mechanical strength of a welded joint. In this paper large number of welding defects as well as different type of failures is analyzed using the final temperature of the welding process which is having great effect on the granular structure of the welded joint.***

Key words: Process parameters, Mechanical strength, friction stir welding, and heat affected zone.

I. INTRODUCTION

Friction Stir Welding (FSW) is invented in 1991 by the Welding Institute of Cambridge. It is a solid state welding process invented by Wayne Thomas et al. and lots of researches have been done in this area all the thermo-mechanical properties are subjected to be study [1].

The mechanical properties of any welded joints are mainly affected by distribution of different properties across the heat affected zone [3]. Development of the grain structure and surface of the welded joints depends on the condition of the thermo mechanical zone [5].

Friction stir welding is a continuous, autogenous, hot shear process which involves non consumable tool made by hard material than the base metal [2]. This is mainly used for aluminum alloys as well as titanium, steel and other metal also. Welding of aluminum alloy is a very typical task because of high thermal conductivity [7].

FSW is an advantageous process which does not requires any type of filler material; this also reduced the cost of welding process [5]. There is a great difficulty while joining dissimilar metals but FSW is able to join similar as well as dissimilar metals; it is done by great heat flow and material movement [11].

Heat is generated due the friction generated between the work piece and tool pin which is attached to the shoulder due to continuous rotation of tool [6]. The tool pin and its shoulder are subjected to modification in different manner to affect the flow of material and micro- structural formation.

This process is especially well suited to butt and lap joint in aluminum. It is difficult to weld aluminium using arc welding and other welding processes [4]. In this paper input variables such as speed of welding, speed of shoulder rotation and pin diameter investigated for the influential effect on the weld strength, it is very important to have a set of such optimal values which provide best strength to the weld joint [8].

II. METHODOLOGY

The method involves some steps which involve study about the material, formation of objectives and their constraints which are given as follows:

A. Material

In this paper Al 6061 alloy is used for investigation purpose various experimental data on this material is collected to get the better results and the composition of this material is as follows:

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TABLE I
CHEMICAL COMPOSITION OF ALUMINUM ALLOY 6061

Component	Al	Mg	Si	Ir	Cu	Zi	Ti	Mn	Cr	other
Amount (wt %)	Balance	0.8-.12	0.4-0.8	0.7	.15-.40	0.25	0.15	0.15	.04-.35	.05

TABLE II
PHYSICAL PROPERTIES OF ALUMINUM ALLOY 6061

Physical property	Density (Kg/mm^3)	Melting point (˚C)	Modulus of elasticity (GPa)	Poisson's ratio
Base Metal (6061)	2700	580	70-80	0.33

TABLE III
MECHANICAL PROPERTIES OF ALUMINUM ALLOY 6061

Mechanical property	Yield strength (MPa)	Ultimate tensile strength (MPa)	Hardness number (BHN)	% elongation	Thermal conductivity (W/mK)
Base Metal (6061)	235	283	95	10-14	180

1) Main behavioral properties of Al 6061 involve

a) Good toughness and better surface finish.
b) It is highly corrosive resistant as well as widely available
c) Excellent weldability and workability
d) It can be easily anodized

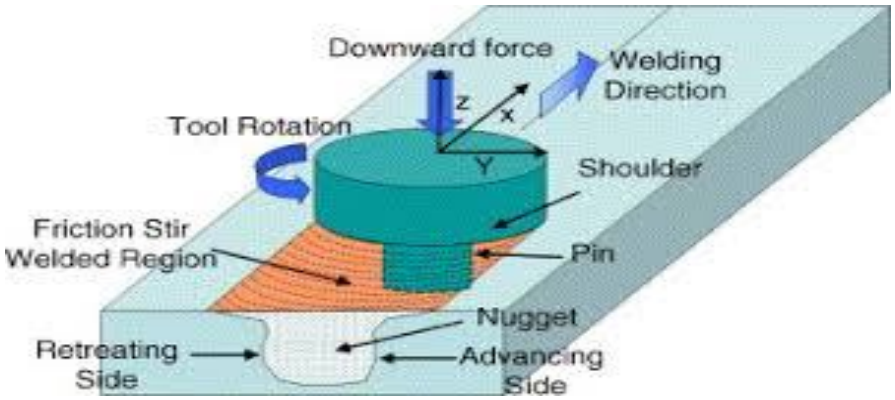

Fig.1 Friction stir welding process

B. Selection of FSW variable process parameter using their impact

It is a basic step to get the various effects on the weld strength which is subjected to many input variables such as Spindle speed, transverse speed or Welding speed, pin profile, probe length, tilt angle, Tool pin diameter and Axial force. Out of all these factors some factors are selected as the most important on the basis of their effect on the weld strength which involves both tensile as well as yield strength.

1) Axial force (F): Axial force is directly affects the mechanical properties of the welded joints. Tensile as well as yield strength is highly affected due to the changes in axial force.
2) Welding speed(S): Welding speed is also known as transverse speed or rate of transverse. This affects the temperature of welding zone inversely. If there is a need to fabricate an alloy with higher yielding strength so lower welding speed is suggested and vice versa. That's why it is an influencing parameter.

3) *Spindle speed (N):* The spindle speed is the frequency of rotation of the machine's spindle, which is measured in revolution per minute (RPM). The spindle speed is chosen on the basis of the material is being cut. More increment in the spindle speed will result in wearing of tool, breakages and various defects such as chattering of the tool which results in dangerous condition. It means that tool life is increased with the help of correct selection of spindle speed for the particular material. As spindle speed increases so the temperature of the heat affected zone is also increased. That means there is a basic need to identify the optimal range of spindle speed.
4) *Tool pin diameter (D):*Tool pin diameter as well as tool profile affects the tensile strength because the shape has impact on the stirring phenomenon as well as grain structure.

C. Check the impact of each process parameter on the failure of the welded joints

All the process parameters affect the microstructure of the welded joint and this happens due to the temperature which rises during the welding process. This indicates that all the parameters should be analyzed to evaluate their effects on the failure of the welded joint.

D. Formation of the objective function with its constraints

In friction stir welding process lots of factors make big differences in the mechanical properties of the welded joints, mainly two properties which are tensile and yield strength tell about the welding quality. Main objective is to maximizing these both strengths using the variable which has a particular highest value.

Tensile strength (TS) or Ultimate tensile strength (UTS) is defined as the maximum stress that a material can stand while being pulled or stretched before any cracking or necking and the yield strength (YS) is defined as the stress at which a material starts to deform plastically. The material can't returns to its original structure when the applied stress is removed.

Maximizes to,

$$\text{(Ultimate tensile strength (UTS))}\ \sigma = f(F, S, N, D) \tag{1}$$

$$\text{(Yield strength (YS))}\gamma = f(F, S, N, D) \tag{2}$$

E. Evaluation of the heat generation and the final temperature

Heat generation is analyzed to evaluate the final temperature value after welding and generation of heat is also depending on all these influencing parameters. The heat generation is given by the following equation.

$$q = (2\pi/S)\mu NFR\eta \tag{3}$$

After calculating the value of generated heat another equation is used to evaluate the final temperature which is given here;

$$q = mC_V\Delta T \tag{4}$$

F. Set the optimal range of the selected parameters

There is a basic need to check the optimal values of all parameters to fix the value of tensile and yield strength at their best level. In this paper temperature is used to evaluate the values of different parameters. Temperature has the highest value which is the melting point (528˚C) of the used material which is Al 6061.

III. CALCULATION AND ANALYSIS

Different types of failures and defects are analyzed to obtain the optimal values of different process parameters. Large number of values are selected to be studied, In this paper range of different parameters are investigated on the basis of their experimental

values which are collected from different papers and the optimal set of these factors is obtained.

TABLE IV
VALUES OF DIFFERENT PARAMETERS

S.No.	Influencing factor	Level 1	Level 2	Level 3
1	Axial force(F)	7 KN	10 KN	15 KN
2	Welding speed(S)	50 mm/min	75 mm/min	90 mm/min
3	Spindle rotation(N)	550 rpm	1000 rpm	1250 rpm
4	Tool pin diameter(D)	8 mm	10 mm	12 mm

A. Effect of axial force on tensile strength and yield strength

In FSW process, a large amount of heat is produced due to the tool rotation which also brings the metal to plastic state in which it becomes very hot. The axial force is highly responsible for the depth of plunge of the tool pin into the work piece. Basically material joining process is highly influenced by the extrusion process due to axial force and the toll pin movement which rotate into the plastic zone of hot material. Ultimate tensile strength of the welded joint is increased due to the increment of axial force and follows the same manner as followed by spindle rotation.

TABLE V
VALUES OF ULTIMATE TENSILE STRENGTH AND YIELD STRENGTH FOR DIFFERENT AXIAL FORCE

S.No.	Axial force(F)	Ultimate tensile strength (MPa)	Yield strength (MPa)
1	7 KN	145	30
2	10 KN	189	50.25
3	15 KN	130	89.175

B. Effect of welding speed on tensile strength and yield strength

Ultimate tensile strength of the welded joint is basically depends on the state that how metal mixes and what type of structure is formed due to the particular speed, it is noticed that the frictional heat input to the work material is decreased due to higher welding speeds and this phenomenon creates poor plastic flow of metal which results in various defects such as tunnel defect, voids etc. this also restricts growth of grains, So that less tensile strength is achieved. Welding speed effects on grain structure is analyzed to check the influence on microstructure of welded joint.

TABLE VI
VALUES OF ULTIMATE TENSILE STRENGTH AND YIELD STRENGTH FOR DIFFERENT WELDING SPEED

S.No.	Welding speed(S)	Ultimate tensile strength (MPa)	Yield strength (MPa)
1	50 mm/min	165	881.9
2	75 mm/min	180	363
3	90 mm/min	185	244

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C. Effect of spindle rotation on tensile strength and yield strength

Ultimate tensile strength of the welded joint is increased due to the increment in the spindle speed and it reaches to the highest value then it decreases after further increment in the spindle speed. It happens because heat input increases per unit joint length with the rotational speed increment. Improved ultimate tensile strength is can be achieved due to a uniformly distributed grain structure which is obtained with the help of high heat input at the higher rotation speed. If the welding speed is further increased so there will be heavy material released on the outer layer of the welded joint which arises the problem of surface defects.

TABLE VII
VALUES OF ULTIMATE TENSILE STRENGTH AND YIELD STRENGTH FOR DIFFERENT SPINDLE ROTATION

S.No.	Spindle rotation(N)	Ultimate tensile strength (MPa)	Yield strength (MPa)
1	550 RPM	96	75
2	1000 RPM	190	187.58
3	1250 RPM	122	263.04

D. Effect of Tool pin diameter on tensile strength and yield strength

Ultimate tensile strength of the welded joint is not much affected due to the pin radius and heat generation in the welding zone is highly affected due to this. Tool pin radius is directly proportional with the heat generation. If the diameter of shoulder is large, then there will be high heat generation due to large contact area. It has also been analyzed small area contact will result in less frictional heat generation. So that there is a basic requirement to obtain a optimized value of pin radius. In this paper three different diameter are selected to check their optimality for the maximum tensile strength.

TABLE VIII
VALUES OF ULTIMATE TENSILE STRENGTH AND YIELD STRENGTH FOR DIFFERENT TOOL PIN DIAMETER

S.No.	Tool pin diameter(D)	Ultimate tensile strength (MPa)	Yield strength (MPa)
1	8 mm	131.3	253
2	10 mm	133.78	310.33
3	12 mm	134.29	365

IV. RESULTS AND CONCLUSION

Analysis and calculation represents the different behavior of the welded joint with respect to all process parameters. Spindle speed of rotation affects the ultimate tensile strength and yield strength in the same manner where the both strengths have lower value at 550 RPM and it increases with the speed increment and reaches to the highest value. It is found that changes in tool pin radius affect the both strength in the similar manner. In case of axial force tensile strength is having frequent changes and yield strength increases up to its maximum value.

In this paper a wide variety of parameters is analyzed which suggest that there should be a formation of a analytical model where a set of values can be placed to get the required set of strength and other mechanical properties. Here the other factors are kept constant to obtain the particular parameter behavior. All the values are obtained with the help of different data collection from experimenting papers.

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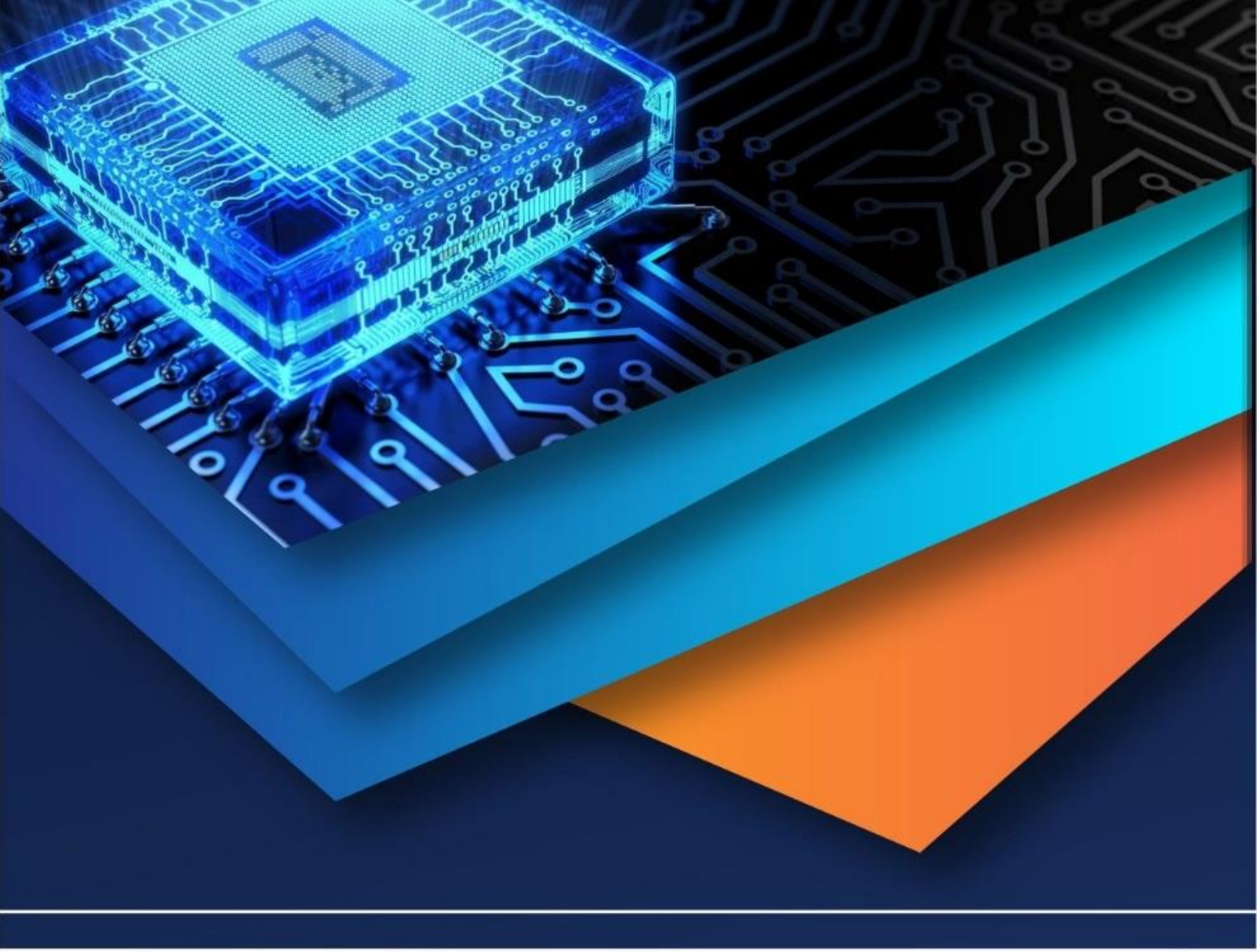

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