EFFECT OF WELDING PARAMETERS ON THE MECHANICAL PROPERTIES OF FRICTION STIR WELDED DISSIMILAR ALUMINIUM ALLOYS 6101 & 6082

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ABSTRACT

Welding is a joining process in which similar or dissimilar metals or alloys are joined by the application of heat with or without the aid of pressure. Friction Stir Welding (FSW) is relatively a new solid state joining process. This joining technique is energy efficient, environment friendly, and versatile. In particular, it can be used to join high strength aerospace aluminium alloys and other metallic alloys which are hard to weld by conventional fusion welding. The need for joints between dissimilar materials often arises in complex industrial applications. Therefore dissimilar-metal welding procedures are necessary for the manufacturing of a number of parts and structures in the industry. The applications of welding technologies is useful not only during production but also during repair or recycling process, therefore, new, economic, environmentally friendly technologies are being developed. In this investigation, Friction Stir Welding Process was used to weld the dissimilar aluminium alloys 6101 and 6082. The main objective of this research work was to study and optimize the effect of various welding parameters on the mechanical properties i.e. Tensile Strength and Impact Strength of friction stir welded joints. The welding parameters used to weld the aluminium alloys were Tool Rotational Speed, Welding Speed and Tool Pin Diameter. After conducting the experiments, it has been seen that the mechanical properties improve with increase in tool rotational speed and decrease with increase in welding speed. Also, the mechanical properties were found better in specimens welded with larger tool pin diameter.

Keywords: - *Friction Stir Welding, Aluminium Alloys, Welding Parameters, Mechanical Testing.*

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1. INTRODUCTION

Aluminium alloys have been widely used in many fields such as the construction, transportation and aerospace owing to their excellent performance, including light weight, high strength and ductility, good corrosion resistance and abundant resources. Aluminium alloy has an extensive range of industrial applications due to its consistent mechanical properties and structural integrity. Aluminium alloys are more frequently welded than any other types of nonferrous alloys because of their widespread applications and fairly good weldability. Welding is one of the most common joining methods for aluminium alloys.

In recent years, friction stir welding (FSW) has been found to be very effective for the welding of various wrought aluminum alloys [14]. Friction stir welding is a new welding technique for aluminium alloys invented by The Welding Institute, Cambridge, U.K., in 1991[19]. Friction stir welding (FSW) is an innovative welding process commonly known as a solid state welding process [13]. FSW has been shown to successfully weld aluminium alloys, historically considered difficult to fusion weld, with higher joint efficiencies than conventional methods the manufacturing sector is embracing FSW as a new technology and replacing fusion weld capabilities [3]. The technique can produce joints utilizing equipment based on traditional machine tool technologies, and it has been used to weld a variety of similar and dissimilar alloys. Replacement of fastened joints with Friction Stir welded joints can lead to significant weight and cost savings, attractive propositions for many Industries [8]. Dissimilar metal joining process using friction stir welding is very difficult to achieve because of different co-efficient of heat and the base metal chemical composition and their property make it difficult to choose a proper welding parameters like rotational speed, traverse speed, axial force and tilt angle which plays a vital role in improving the weld quality.

Friction Stir Welding (FSW) is a simple process in which a rotating cylindrical tool with a shoulder and a profiled pin is plunged into the abutting plates to be joined and traversed along the line of the joint. The plates are tightly clamped on to the bed of the FSW equipment to prevent them from coming apart during welding. A cylindrical tool rotating at high speed is slowly plunged into the plate material, until the shoulder of the tool touches the upper surface of the material. A downward force is applied to maintain the contact. Frictional heat, generated between the tool and the material, causes the plasticized material to get heated and softened, without reaching the melting point. The tool is then traversed along the joint line, until it reaches the end of the weld. As the tool is moved in the direction of welding, the leading edge of the tool forces the plasticized material, on either side of the butt line, to the back of the tool. In effect, the transferred material is forged by the intimate contact of the shoulder and the pin profile. It should be noted that, in order to achieve complete through-thickness welding, the length of the pin should be slightly less than the plate thickness, since only limited amount of deformation occurs below the pin. Upon reaching the end of the weld, the tool is withdrawn, while it is still being rotated [10]. The schematic diagram of FSW process is shown in fig. 1.

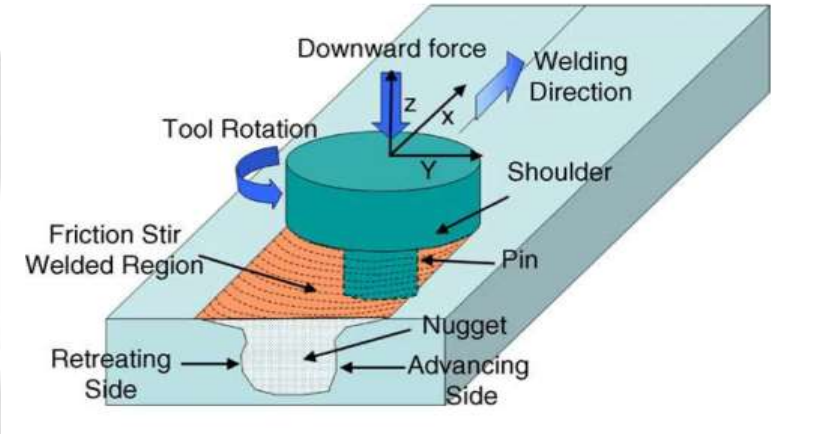

Fig. -1 Schematic diagram of FSW process (Rani et al., 2015)

Friction stir welding is regarded as an asymmetric process mainly due to the material flow being affected by the rotation and translational motions of the tool. This asymmetry is reflected in the shape of the nugget and to some extent on temperature distribution, on either side of the nugget. The side of the weld, where the local direction of the tool is the same as the traversing direction, is called the 'advancing side'. The other side, where the directions are opposite and the local movement of the shoulder is against the traversing direction, is called the 'retreating side' [10].

In the present work, the aim is to investigate the effect of various welding parameters (tool rotation speed, welding speed and tool pin diameter) on mechanical properties of friction stir welded butt joints of dissimilar aluminium alloys 6101 and 6082.

2. EXPERIMENTAL DETAILS

2.1 DESIGN OF EXPERIMENTS

A two level factorial design of eight trails (2^3 =8) were selected for determining the effect of three independent FSW parameters. Tool Rotation Speed, Welding Speed and Tool Pin Diameter were identified as welding parameters for carrying out the experimental work and to find their effect on the mechanical properties (Tensile strength and Impact strength) of FSW joints. Upper and lower levels of the FSW parameters were carefully selected by carrying out the trail runs. The upper level was coded as (+1) and lower level as (-1) or simply (+) and (-).

The units, symbols used and limits of welding parameters are given in the table 1.

Table -1 Welding Parameters and their Limits

Parameters	**Units**	**Symbol**	**Upper Limit (+)**	**Lower Limit (-)**
Tool Rotation Speed	rpm	R	1200	900
Welding Speed	mm/min	S	45	30
Tool Pin Diameter	mm	D	7	6

The design matrix developed to conduct the eight trails run 2^3 factorial design as given in table 2.

Table -2 Design Matrix

S No.	**R**	**S**	**D**
1	+	+	+
2	-	+	+
3	+	-	+
4	-	-	+
5	+	+	-
6	-	+	-
7	+	-	-
8	-	-	-

2.2 EXPERIMENTATION FOR FSW

Friction stir welding (FSW) was carried out using vertical milling machine fitted with cylinder shaped tool. Firstly some trails were performed to finalize the working range of welding parameters. The materials taken for investigation were AA-6101 and AA-6082 alloy having dimension of 150 x 75 x 6 mm. AA 6101 was positioned at advancing side and AA 6082 was positioned at retreating side. Two friction stir welding (FSW) tools with cylindrical pin diameters of 7 mm and 6 mm with pin length of 5.8 mm and shoulder diameter 20 mm were used. The welding tool used in Friction stir welding is shown in fig 2.The tool used in experimentation was made of H13 material. H13 Tool Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The welding was carried out by using a properly designed clamping fixture that allows fixing two plates. According to design of experiment eight experiments were performed with one set of repetition, so total sixteen experiments were performed.

Fig -2 Welding tool

Table -3 Chemical composition (%) of plate AA 6101

Cu	**Mg**	**Si**	**Fe**	**Mn**	**Others**	**Al**
0-0.05	0.40-0.90	0.30-0.70	0.50	0-0.03	0.1	remainder

Table -4 Chemical composition (%) of plate AA 6082

Cu	**Mg**	**Si**	**Fe**	**Mn**	**Cr**	**Others**	**Al**
0-0.10	0.60-1.20	0.70-1.30	0.50	0.40-1.00	0-0.25	0.3	remainder

After welding, the welded specimens are sliced using a power hacksaw and then machined to the required dimensions. Two test specimens i.e. one for tensile test and one for Impact test investigation are obtained from each welded specimen as per ASTM standards.

3. TESTING RESULTS

3.1 TENSILE TEST

The response or the results of tensile testing are obtained by conducting experiment by using design matrix are as in table 5.

Table -5 Tensile Testing Results

S. No.	**Tool rotation Speed (R)**	**Welding speed (S)**	**Tool Pin Diameter (D)**	**Tensile strength (MPa) SET-1**	**Tensile strength (MPa) SET-2**
1	1200	45	7	55	72
2	900	45	7	63	70
3	1200	30	7	71	74
4	900	30	7	70	61
5	1200	45	6	71	70
6	900	45	6	57	61
7	1200	30	6	61	67
8	900	30	6	70	60

3.2 IMPACT TEST

The response or the results of impact testing are obtained by conducting experiment by using design matrix are as in table 6.

Table -6 Impact Testing Results

S. No.	**Tool rotation Speed (R)**	**Welding speed (S)**	**Tool Pin Diameter (D)**	**Impact strength (Joules) SET-1**	**Impact strength (Joules) SET-2**
1	1200	45	7	12	13.5
2	900	45	7	14.5	14
3	1200	30	7	14.5	16.5
4	900	30	7	11.5	10.5
5	1200	45	6	4.5	4
6	900	45	6	6	7.5
7	1200	30	6	14	13.5
8	900	30	6	6	4.5

4. ANALYSIS OF RESULTS

4.1 EFFECT OF TOOL ROTATION SPEED ON TENSILE STRENGTH

It was found that as the tool rotation speed increases the tensile strength increases. When the tool rotation speed increase from 900 rpm to 1200 rpm, the tensile strength increases from 64 MPa to 68 MPa respectively. This is because at higher rotational speed the frictional heat generated is higher. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. The effect of tool rotation on tensile strength is shown in fig. 3.

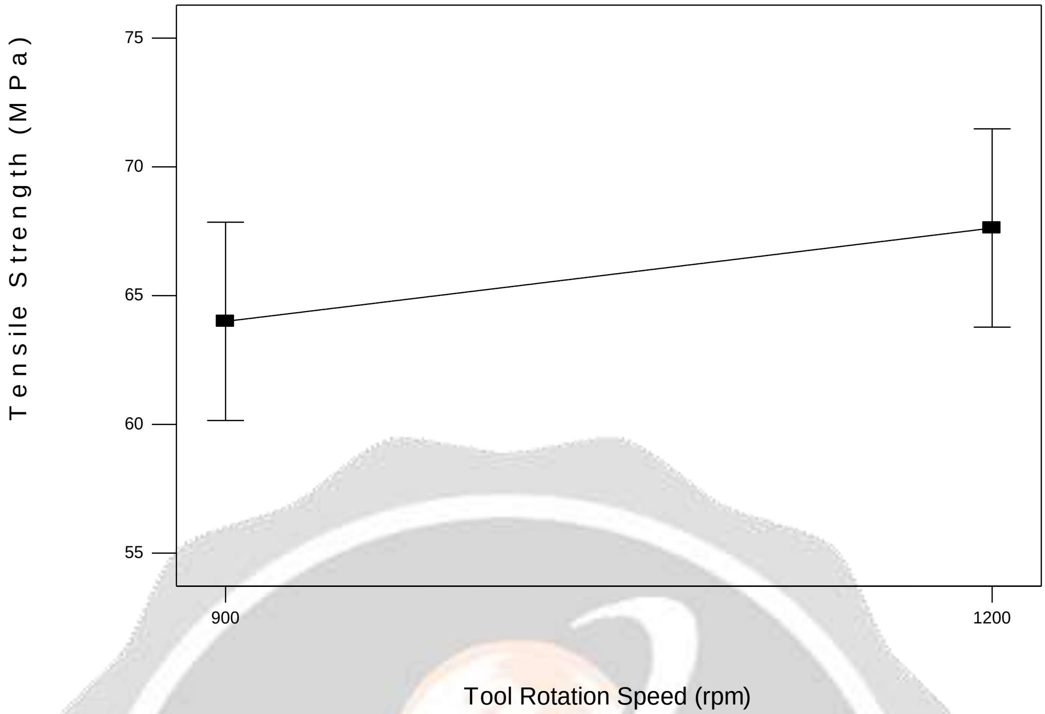

Fig-3 Effect of tool rotation speed on Tensile Strength

4.2 EFFECT OF WELDING SPEED ON TENSILE STRENGTH

It was found that as welding speed increases from 30 mm/min to 45 mm/min, the tensile strength decreases from 66.75 MPa to 64.875 MPa respectively. An increase in the welding speed affects to lesser the tensile strength of the specimen. The lowest welding speed generated high heat input and encouraged metallurgical transformations of the weld zone leading to a higher tensile strength. The highest welding speed discouraged clustering effect of strengthening precipitates, plastic flow of materials and localization of strain due to insufficient frictional heat generated and hence the tensile strength is reduced. Effect of welding speed on tensile strength is shown in fig 4.

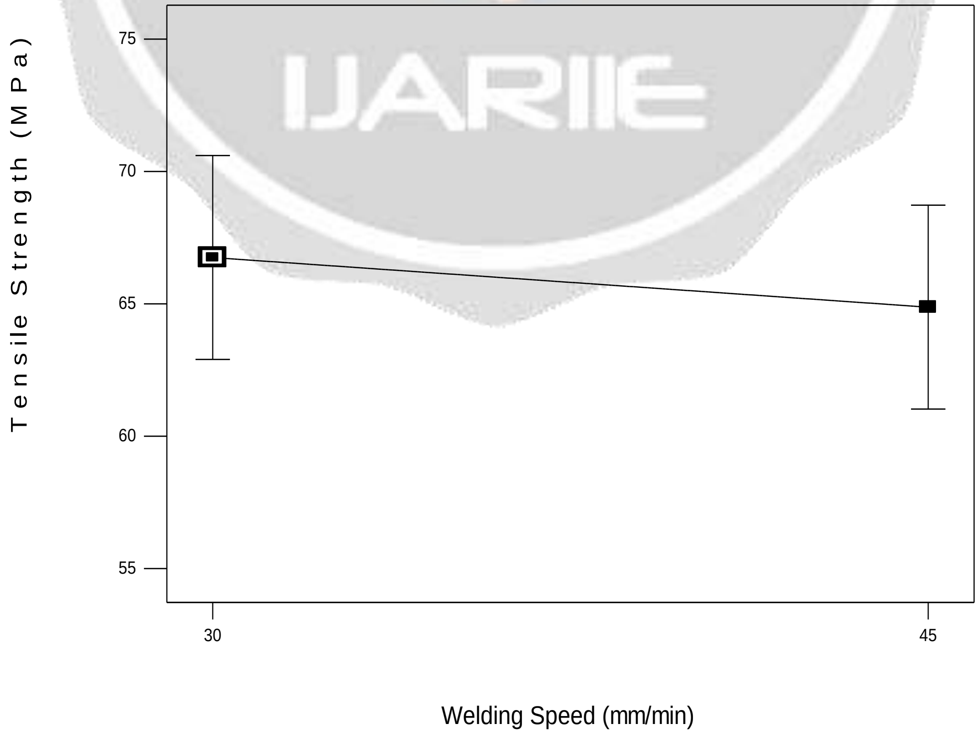

Fig -4 Effect of welding speed on Tensile Strength

4.3 EFFECT OF TOOL PIN DIAMETER ON TENSILE STRENGTH

It was found that as pin diameter increase from 6 mm to 7 mm, the tensile strength increases from 64.625 MPa to 67 MPa respectively. It can be attributed to the fact that as pin diameter increases, more surface area comes under re-crystallization which increases the bonding between the joints, as a result increasing the tensile strength. The effect of pin diameter on tensile strength is shown in fig 5.

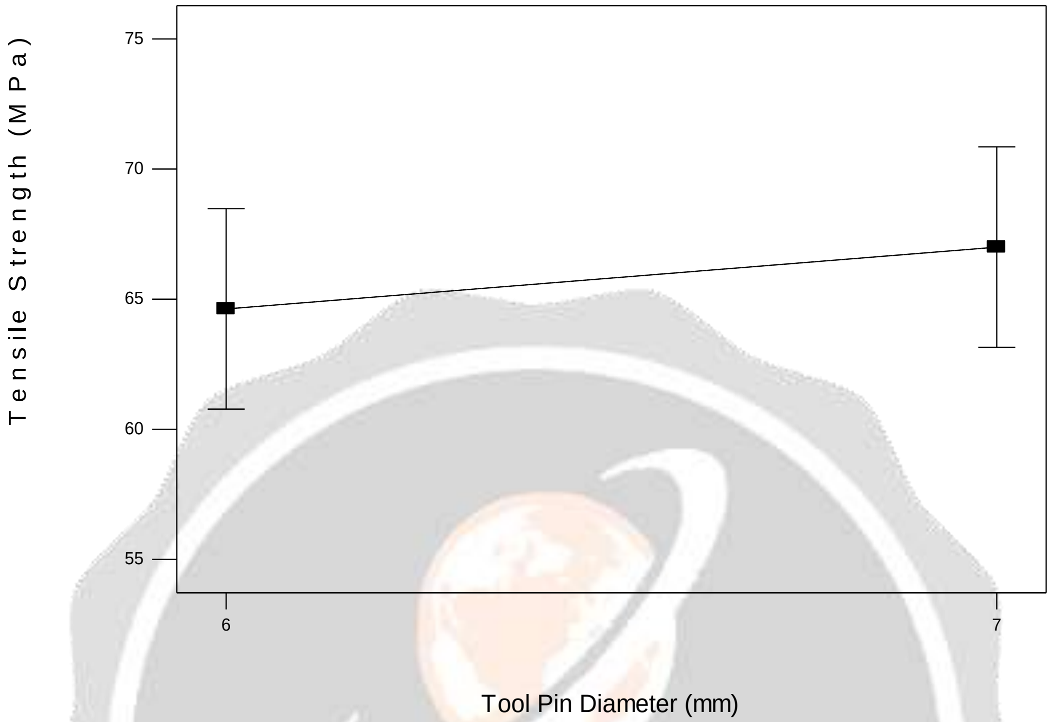

Fig -5 Effect of pin diameter on Tensile Strength

4.4 EFFECT OF TOOL ROTATION SPEED ON IMPACT STRENGTH

It was found that when the tool rotation speed increases from 900 rpm to 1200 rpm, the impact strength increases from 9.31 J to 11.56 J. This is because at higher rotational speed the frictional heat generated is higher. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. Effect of tool rotation speed on impact strength is shown in fig 6.

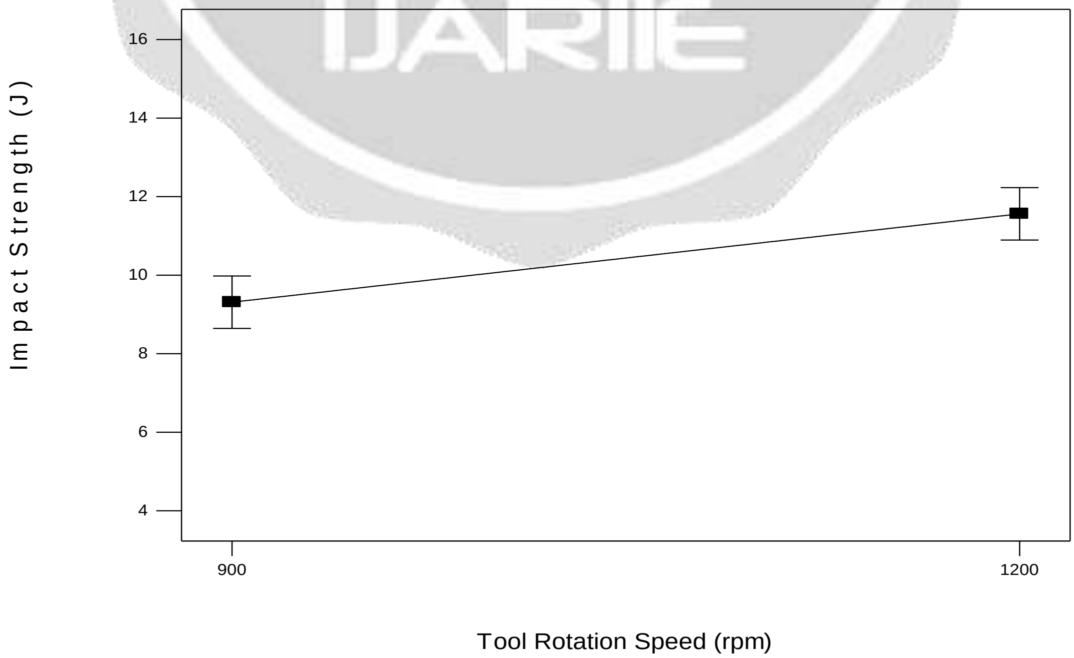

Fig -6 Effect of tool rotation speed on Impact Strength

4.5 EFFECT OF WELDING SPEED ON IMPACT STRENGTH

As the welding speed increases from 30 mm/min to 45 mm/min, impact strength decreases from 11.37 J to 9.50 J respectively. An increase in the welding speed affects to lesser the impact strength of the specimen. The lowest welding speed generated high heat input and encouraged metallurgical transformations of the weld zone leading to a higher impact strength. The highest welding speed discouraged clustering effect of strengthening precipitates, plastic flow of materials and localization of strain due to insufficient frictional heat generated and hence the impact strength is reduced. The effect of welding speed on impact strength is shown in fig 7.

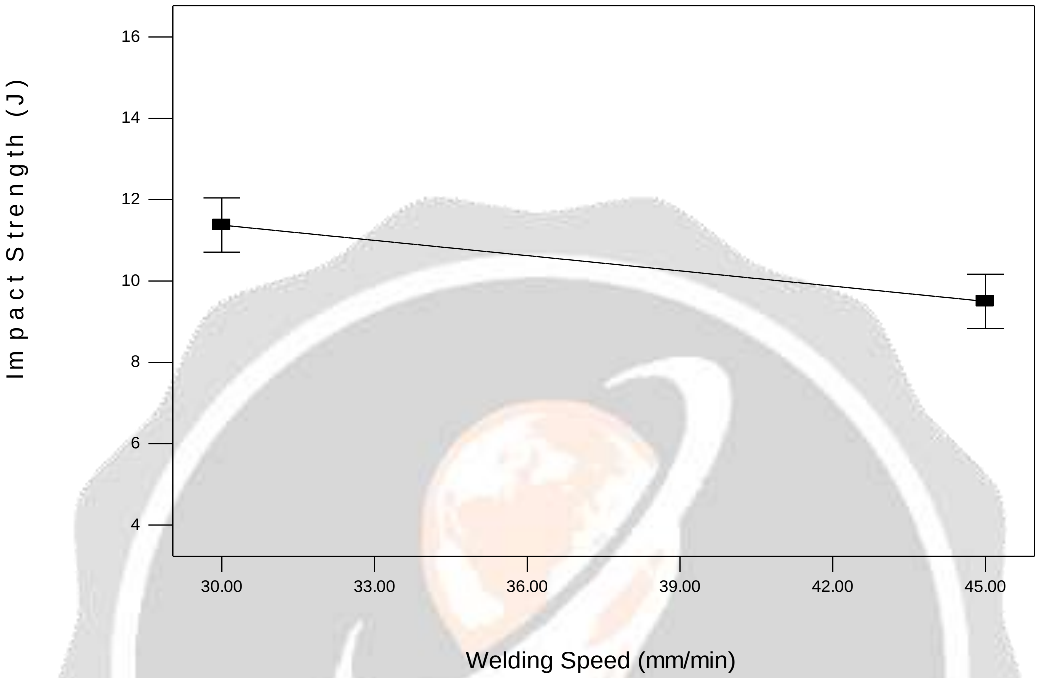

Fig -7 Effect of welding speed on Impact Strength

4.6 EFFECT OF TOOL PIN DIAMETER ON IMPACT STRENGTH

It was found that as pin diameter increases from 6 mm to 7 mm, impact strength increases from 7.5 J to 13.37 J. It can be attributed to the fact that as pin diameter increases, area of contact between joint also increases which increase the bonding between the joints, as a result increasing the impact strength. The effect of pin diameter on impact strength is shown in fig 8.

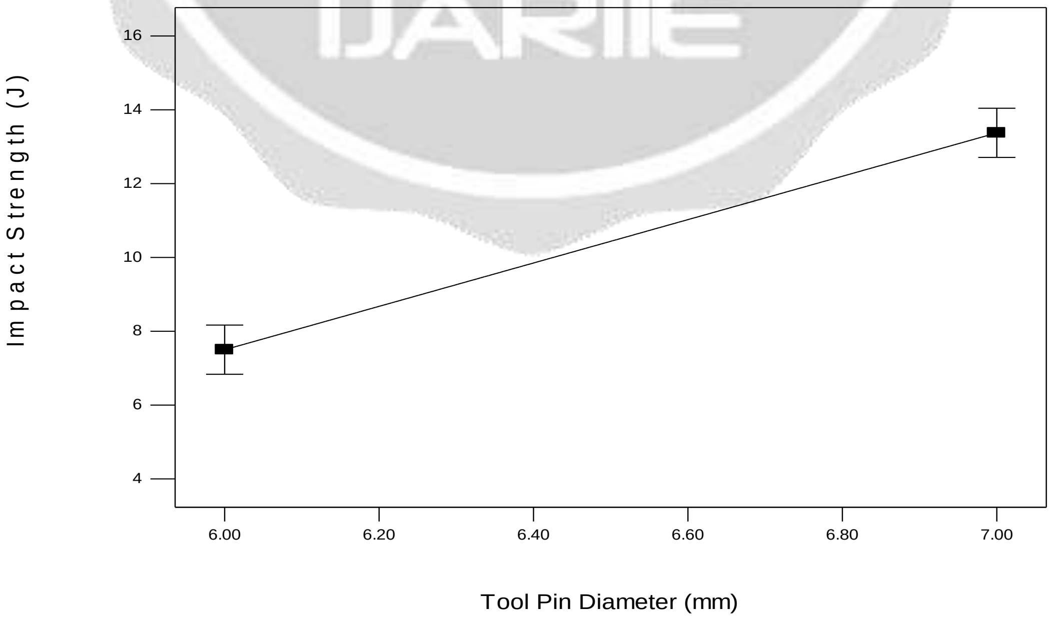

Fig -8 Effect of tool pin diameter on Impact Strength

5. CONCLUSIONS

Following conclusions had been drawn from this research work:

- Tensile Strength was increased with increase in tool rotational speed and was decreased with increase in welding speed. Also at higher level of tool pin diameter, tensile strength was found increased.
- Impact Strength was increased with increase in tool rotational speed and was decreased with increase in welding speed. Also at higher level of tool pin diameter, impact strength was found increased.
- Welding parameters had significant effects on the mechanical properties: tensile strength and impact strength.
- The optimum set of parameters for friction stir welding of dissimilar aluminium alloys 6101 and 6082 using is the set of parameters where tensile strength and impact strength is found higher. From the results it was found that tensile strength and impact strength is maximum at tool rotation speed **1200 rpm, welding speed 30 mm/min, and tool pin diameter 7mm**.

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