Mechanical Properties Of Friction Stir Welded 6061 Aluminium Alloy

Rohit Kumar, Ratnesh Kumar Raj Singh, Dr. A K Bajpai

[1]M.Tech Student , Department Of Mechanical Engineering , Madan Mohan Malaviya Engineering college, Gorakhpur , U.P, INDIA

[2]Research Scholar, Department Of Applied Mechanics, IIT Delhi, New Delhi, India

[3]Professor, Department Of Mechanical Engineering , Madan Mohan Malaviya Engineering college, Gorakhpur , U.P, INDIA

Abstract

The objective of this work is to produce sound weld of 6061 Aluminium alloy (T6) by Friction Stir Welding (FSW) Process and investigate the tensile properties of joints in terms of process parameters. The joint efficiency is found maximum of 83.33 % and minimum of 36.67. This work also focuses on problems associated with the welding of aluminum alloys with the help of conventional welding processes and its solutions by FSW. FSW is one of the important welding process that can be adopted for welding of Aluminium alloys with excellent mechanical properties.

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1. Problems Associated With Conventional Welding Processes or Need of Friction Stir Welding Process

It is difficult to make high strength, fatigue and fracture resistant weld of aerospace aluminum alloys, such as highly alloyed 2xxx, 6xxx and 7xxx series which are more frequently used in ship building and aerospace applications. These aluminum alloys are generally classified as non-weldable because of their poor solidification microstructure and due to the porosity in weld region. Also there is a significant loss of mechanical properties as compared to the base material. Some aluminum alloys can be resistant-welded but the surface preparation is expansive as well as problem of surface oxide occurs [1].

Now these aerospace aluminum alloys can be easily welded by the means of friction stir welding process.

2. Invention of Friction Stir Welding

Friction stir welding was firstly invented at The Welding Institute of UK in 1991, as a solid-state joining technique and was initially applied to aluminum alloys [2, 3].

3. Basic Working Principle of Friction Stir Welding

The working principle of fiction stir welding is quite simple. In friction stir welding process, a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of plates or sheets to be joined and is transverse along the line of joint. A schematic drawing of

Friction Stir Welding process is shown in the fig.1.

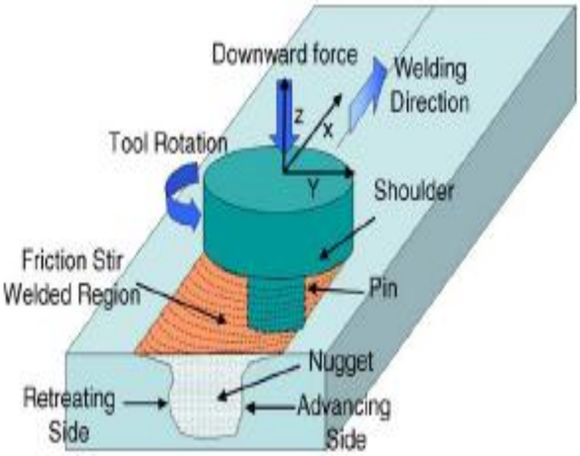

Fig. 1 Schematic Diagram of Friction Stir Welding process [1].

The heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state'. Because of various geometrical features of the tool, the material movement around the pin can be quite complex [4].

During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains [5-8].

4.Why 6061 Aluminium Alloy ?

6061 is a precipitation hardening aluminium alloy containing magnesium and silicon as its major alloying elements.

This alloy has Si (0.4-0.8%), Fe (max 0.7%), Cu (0.15-0.40%), Mg (0.15), Cr (0.04-0.35%), Zn (max. 0.25%) and Ti (Max. 0.15%).

This alloy is highly weldable by Tungsten inert gas welding and by Metal inert gas welding. Typically after welding, the properties near the weld are those of 6061-O, a loss of strength about 80 %. 6061 is commonly used for aircraft wings, fuselages, small utility boats, tanks, fly fishing reels and bicycle frames etc.

5. Welding Procedure

Making welds of 6061 Aluminum Alloys plates having dimensions 200 mm x 50 mm x 6 mm (as given in Fig. 2) first on trial basis to set the parameters range and then using full factorial design of experiment method with varying welding speed and rotational speed as a design factors. All other factors are remains constant [5,6]. The tool used for friction stir welding have 7 mm pin diameter and 20 mm shoulder diameter with left hand threaded pin of 1 mm pitch. The tool material is of EN31 die steel.

A range of maximum and minimum values of welding parameters are taken into consideration in order to make welds of aluminium alloys. Minimum and maximum range of parameters are given in the Table 1. The top and bottom surfaces of weld are shown in fig. 3.

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Table 1- Range of parameters

Parameters	**Low Values (-1)**	**High Values (+1)**
Welding Speed (mm/min)	200	400
Rotational Speed (rpm)	355	560

Using Full Factorial method of the Design Expert the no. of welding run are coming 4 as given in Table 2.

5. Preparation of Samples for Tensile Testing

Samples were prepared for tensile testing in the transverse direction of welding as per **ASTM E8-M standard**. Sample were cut by power saw of around 13-14 mm width and then shaper it to 10 mm width by shaper machining. The reduced section were prepared by end milling cutter. Samples cutted from the welds in order to make specimen for tensile testing are shown in the Fig.4.

Table 2- Welding Parameters

Welding Run	Rotational Speed (rpm)	Welding Speed (mm/min)
1	355 (-1)	200(-1)
2	355 (-1)	400(+1)
3	560 (+1)	200 (-1)
4	560 (+1)	400 (+1)

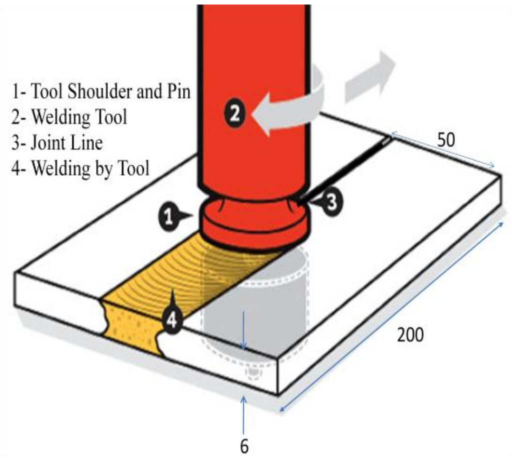
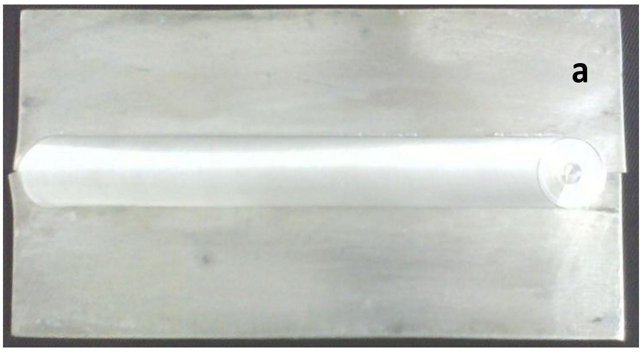


Fig.2 Welding diagram showing tool and work piece.



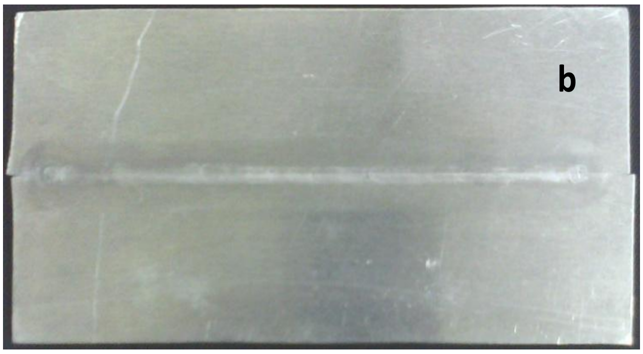


Fig.3 Welded plates by FSW showing (a) top and (b) bottom surface.

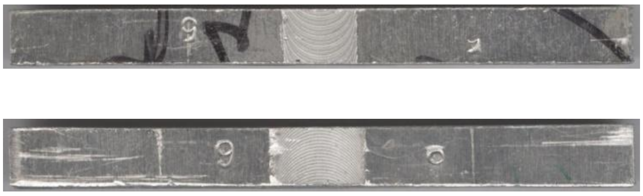


Fig.4 Sample cutted from the welds in transverse direction

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Before testing each samples were polished by different grade of emery paper (from 220 to 1000) with using kerosene oil to remove all type of surface irregularities occurs during machining. The strain rate kept constant for all samples are 1 mm/min [6]. The ultimate tensile strength is taken as 100% joint efficiency of base material. Dimensions of tensile test specimen are shown in the Fig.5 while samples prepared for tensile testing are shown in the Fig.6. Similar tensile test specimen are also prepared from the base metal which is shown in the Fig.7.

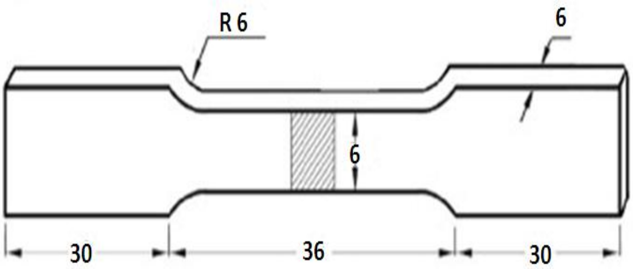

Fig.5 Schematic Diagram of Tensile test specimen.

Fig. 6 Tensile Samples prepared from the Welds.

Fig.7 Tensile Sample prepared from the base metal.

6. Results

The tensile properties obtained from the tensile test of samples extracted from the base materials of 6061 aluminum alloy and from the weldments in transverse direction of weld. For the better assessment of tensile behaviour, test for each type of samples performed three time and average is presented.

Fig.8 represents the ultimate tensile strength in MPa of base metal and welds which shows that the ultimate tensile strength increases with the welding speed.

Fig.9 represents the elongation in % observed in base metal and welds shows that the elongation in percentage of weld 2 is comparable to base metal.

Fig.10 represents the efficiency of joints of base metal and welds where the joint efficiency of base metal is taken as 100% which shows that the joint efficiency of weld2 is very closed to base metal.

Fig.11 represents the impact strength in MPa of base metal and welds shows that the impact strength of welds welded at higher welding speed is more.

Fig.12 represents the yield strength in MPa of base metal and welds welded at different welding parameters which shows that the yield strength of welds welded at higher welding speed is more.

Similarly fig.13, 14, 15, 16 and 17 shows the variation in yield strength, ultimate tensile strength, elongation, charpy impact strength and joint efficiency(in %) respectively with respect to(w.r.to) the welding parameters obtained by the use of Design Expert.

7. Co-relation of parameters using 'Design Expert'

the various correlations of different welding parameters and mechanical properties are given billow

Yield Strength = + 286.95122 - 0.76939 * Welding Speed + 0.053659 * Rotation Speed + 8.29268E-004 * Welding Speed * Rotation Speed

Ultimate Tensile Strength = +286.95122 - 0.76939 * Welding Speed + 0.053659 * Rotation Speed + 8.29268E-004 * Welding Speed * Rotation Speed

Elongation = +5.97317 - 0.015305 * Welding Speed + 0.019512 * Rotation Speed - 1.46341E-005 * Welding Speed * Rotation Speed

Charpy Impact Strength = +71.46341 - 0.090976 * Welding Speed - 9.75610E-003 * Rotation Speed + 7.31707E-005 * Welding Speed * Rotation Speed

Joint Efficiency = +94.09585 - 0.25229 * Welding Speed + 0.017561 * Rotation Speed + 2.71951E-004 * Welding Speed * Rotation Speed

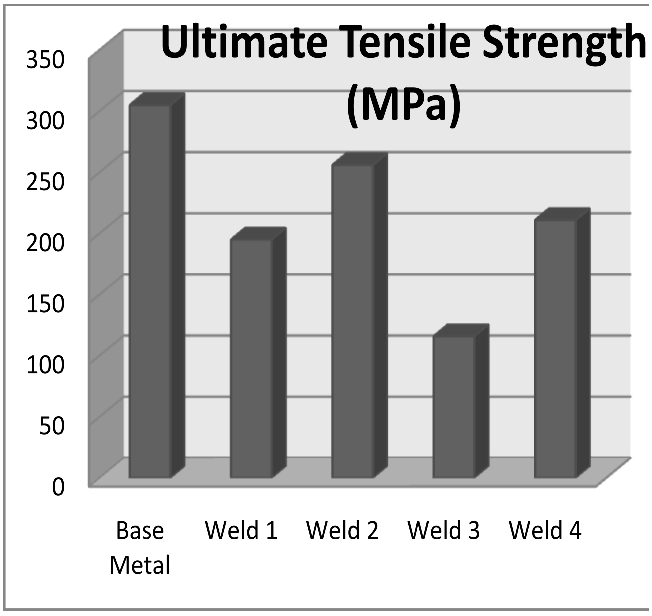

Fig.8 Ultimate Tensile Strength of base metal and welds.

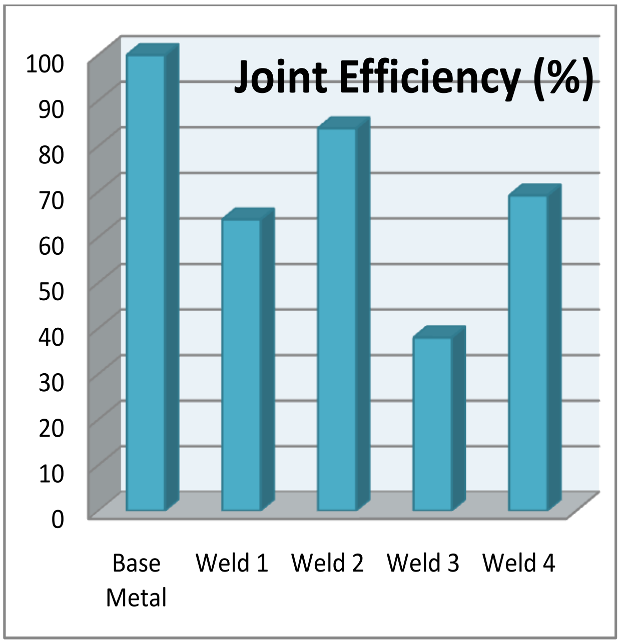

Fig.10 Joint Efficiency in % of base metal and welds.

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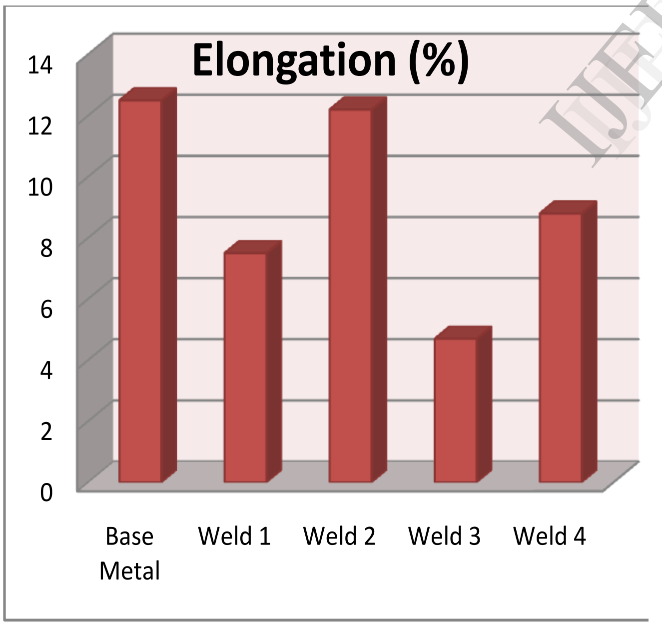

Fig.9 % Elongation of base metal and welds .

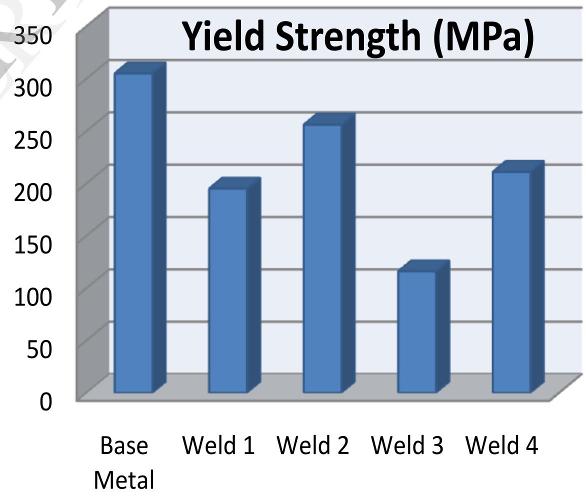

Fig.12 Yield Strength (in MPa) of base metal and welds.

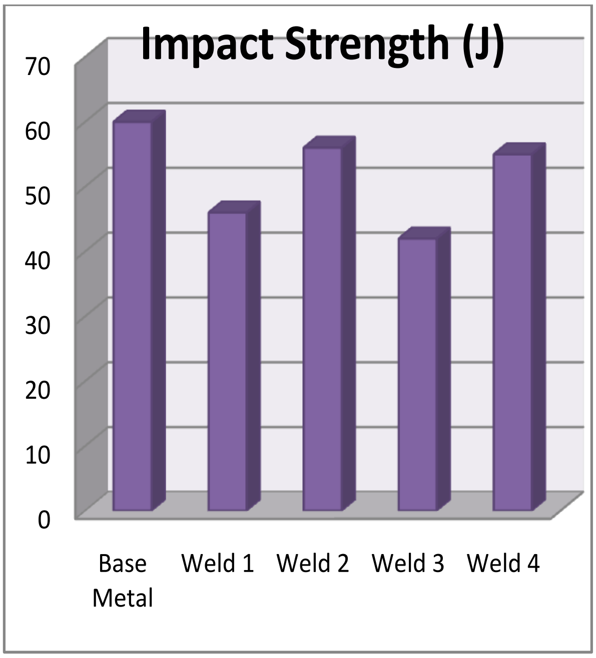

Fig.11 Impact Strength of base metal and welds.

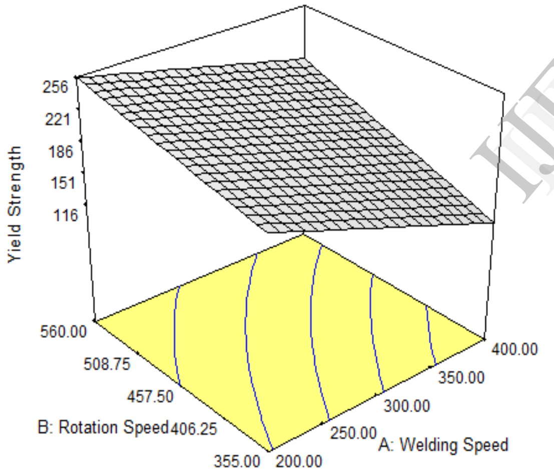

Fig.13 Variation in Yield Strength w.r.to the welding parameters by the use of Design Expert.

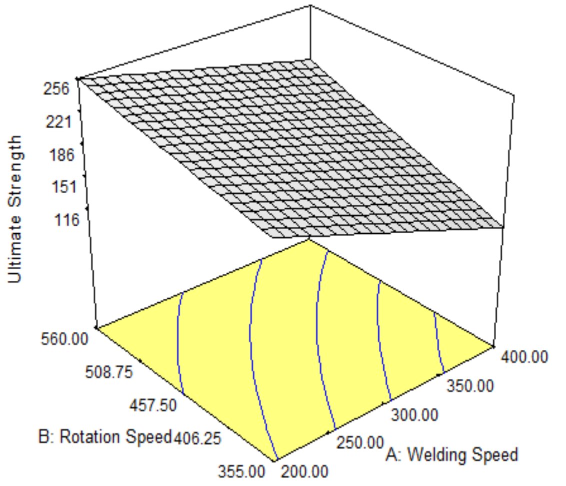

Fig.14 Variation in Ultimate Tensile Strength w.r.to the welding parameters by the use of Design Expert.

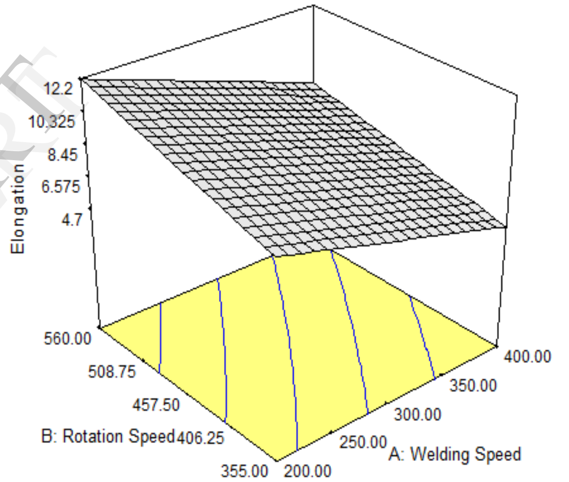

Fig.15 Variation in Elongation w.r.to the welding parameters by the use of Design Expert.

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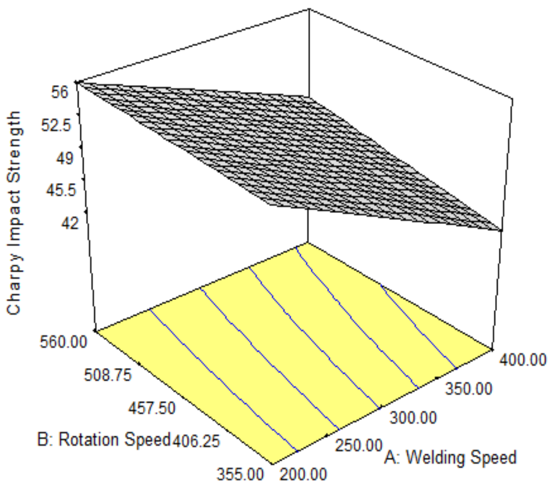

Fig.16 Variation in Charpy Impact Strength w.r.to the welding parameters by the use of Design Expert.

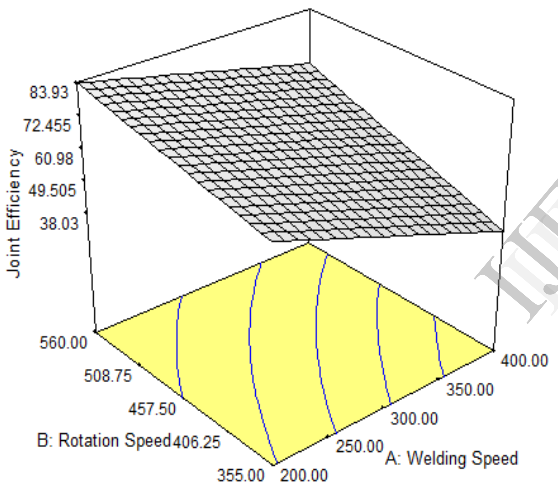

Fig.17 Variation in Joint Efficiency(In %) w.r.to the welding parameters by the use of Design Expert.

8. Conclusion

1) Ultimate tensile strength is directly proportional to the welding speed.

2) Ultimate tensile strengths of welds at higher welding speed are comparable to those of the base metal.

3) Results of this study have demonstrated the feasibility of FSW technique for joining of aluminum alloys without loss of tensile properties. Based on these results, this new technique can be used for other materials too.

4) The highest joint efficiency of 83.93 % was obtained for weld 2.

9. References

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