PROCESS PARAMETERS OPTIMIZATION OF FSW OF AA6061 ON LOW RPM FSW SETUP OF MILLING MACHINE

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ABSTRACT

Friction stir welding (FSW) is a recent developed welding process to join soft materials like aluminum, copper, magnesium, titanium and their alloys. Welding of soft materials is a very difficult task, but FSW makes it possible to weld these materials with best accuracy. The main advantage of this welding process is that, it is a solid state welding process, means the joint get develop without melting the work piece. A cylindrical tool with a profile probe gets inserted into the work piece to create the joint. The main process parameters of this welding process are tool rotation speed, tool feed or transverse speed and impinging pressure. In this study the welding of AA6061 is done on varying tool feed keeping tool rotation and impinging pressure constant and on the basis of mechanical properties of the joint, the best parameters found for the welding of AA6061 on the low RPM milling machine FSW set up.

Keywords: Friction Stir Welding (FSW), AA6061, Solid State, Probe, and Milling.

I. INTRODUCTION

Welding of aluminum and aluminum alloys is very difficult. There are so many considerations which make aluminum and its alloys difficult to weld. Some of these are listed below:

a) The first consideration is the effect of the oxide film present on the surface of the aluminum. Some part of moisture present in this film, which may react during fusion welding with the liquid metal in the weld pool, this thing form oxide again and liberate hydrogen which can cause porosity. Hence it becomes necessary to remove this film mechanically or chemically from the surface before welding.

b) Aluminum is a very good conductor of heat, hence dissipates heat at a very fast rate from the joint being welded to the adjacent base metal. To remove this effect work pieces should be preheated before welding.

c) There should be proper joint design, edge preparation and preheating before welding to remove the distortion effect because aluminum has high coefficient of linear expansion.

d) Aluminum is week when hot and thus extra care is required when welding thinner sections which may buckle.

e) During welding cracks may develop in the aluminum alloys in the weld metal due to its low strength around the solidus of the freezing pool or in the overheated zone of the parent metal due to fusion of low melting point constituents. Cold worked or peened weld metal is attacked more readily than annealed metal, especially under severer corrosive conditions, but the corrosion may be less on a weld that has been hammered smooth than on an unhammered weld because the smoother surface exposes a smaller area.

f) Aluminum does not show any color change on heating and without experience or control it may be difficult to judge when the metal begins to melt or when the proper welding temperature has been reached. There are basically two indicators that the welder however should watch are, the melting of the dry flux and blistering of the metal surface, which shows that a proper welding temperature has been attained [1].

Most alloys of aluminum can be weld easily by TIG and MIG welding processes, but there are some problems associated with these processes such as porosity, lack of fusion due to oxide layers, incomplete penetration, cracks and undercut. They can also be welded by other methods such as, Resistance Welding, Friction Welding, Stud Welding and Laser Welding.

There are some aluminum alloys which have which have some issues while welding conventionally (TIG & MIG). The 2XXX series of aluminum alloys have poor weld ability because of copper content which causes hot cracking and poor solidification microstructure and porosity in the fusion zone. The 5XXX series of aluminum alloys with more than 3% of Mg content is susceptible to cracking due to stress concentration in corrosive environments, so high Mg alloys of 5XXX series of aluminum should not be exposed to corrosive environments at high temperatures to avoid stress corrosion cracking. All the 6xxx series of aluminum are readily weld able but are sometimes susceptible to hot cracking under certain conditions. The 7XXX series aluminum alloys both weld able and non-weld able depending on the chemical composition of the alloy.

All the problems associated with the welding of these different alloys of aluminum has lead to the development of solid state welding processes like Friction Stir Welding technique which is an upgraded version of the friction welding processes. This process has many advantages associated with it, and it can weld many aluminum alloys such as 2XXX and 7XXX series which are difficult to weld by fusion welding processes [2].

II. FRICTION STIR WELDING (FSW)

This new technique of welding was invented in 1991 by Wayne Thomas of TWI (The Welding Institute) of United Kingdom. For the FSW (Friction Stir Welding) the jobs (metal sheets/metal plates) to be joined are aligned and clamped to each other and placed on a backing material. A non-consumable cylindrical tool having a profile probe or pin rotates and plunged in to the joint line. The tool also does a transverse motion along the joining line, this produces the rubbing action and heat is generated which softens the job and the heated soft job material stirred by the probe and plastic flow of material takes place.

This is the solid state welding process in which the material does not reach at its melting point which reduces so many problems like segregation, severer residual stresses, distortion and evaporation of volatile elements. Fig.1 shows the main process.

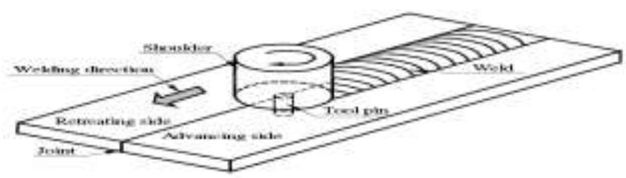

Fig. 1 FSW Process

Originally, the FSW has been develop for joining high strength aluminum alloys and advanced aluminum alloys produced by power metallurgy. Friction Stir Welding in comparison to the automated gas metal arc welding improves the dimensional accuracy of the assembly and produces a 30% increase in joint strength [3].

III. MATERIAL AND METHOD

Aluminium alloys widely used in aerospace, automobile industries, railway vehicles, bridges and high speed ships, because it has light weight and higher strength to weight ratio, corrosion resistance and ductility. In all the discussed areas welding is the most used manufacturing process with a great challenge for designers and technologists.

Aluminium alloy AA6061 (Al-Mg-Si) is the most widely used medium strength aluminium alloy, and has gathered wide acceptance in the fabrication of light weight structures [4].

The Extruded form of aluminium alloy AA6061 is used in the present investigation. It is heat treated up to 300^0C. It was in the sheet form having thickness 5 mm and width 50 mm. Chemical compositions and physical properties are given in Table 1 and 2 respectively.

Table 1 Chemical composition of aluminum alloy AA6061

Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
0.63	0.42	0.42	0.12	0.19	0.05	0.08	0.02	Bal.

Table 2 Physical properties of aluminum alloy AA6061

Density(g/cm^3)	Melting Point(^{0}C)	Modulus of Elasticity(GPa)	Poison Ratio
2.7	600	70-80	0.33

The principle alloying elements in AA6061 are Magnesium and Silicon. Magnesium is introduced in aluminium alloys to increase strength, and recrystalization temperature, allowing the alloy to maintain its strength at high temperatures. Manganese is usually added to aluminium to increase the amount of strain hardening during deformation. Iron is present in aluminium alloys as part of an intermetallic phase which provides a slide increase in its strength as well as better creep properties at moderately high temperatures. Magnesium is added to aluminium to improve its strength properties without sacrificing the alloy's ductility [5].

The mechanical properties are determined from tensile test on 100 kN servo hydraulic control universal testing machine (100 kN ADMET, USA make) under displacement control mode. The hardness of the material is determined by Rockwell hardness testing machine on Rockwell B scale. The mechanical properties of the material are shown in the following Table 3.

Table 3 Mechanical properties of aluminum alloy AA6061

Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)	Reduction in cross sectional area (%)	Hardness (HRB)
280	310	16	11	65

For FSW (Friction Stir Welding) square butt joint is prepared as shown in figure. The thickness of the work piece is 5 mm which is according to the fixture of the machine on which FSW was carried out.

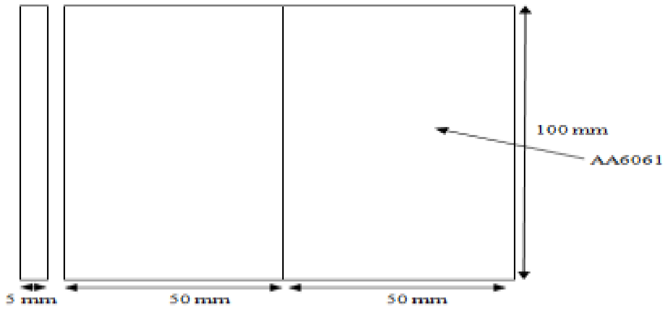

Fig. 2Square Butt Joint for Friction Stir Welding

A non consumable, rotating tool made of die steel is used to fabricate the FSW joint. The set up used for the FSW is oflow rpm milling machine, on which work related to FSW was carried out. The machine setup with joining of the plates is shown in the following Fig. 3.

Fig. 3 FSW Setup on Milling Machine

The main component in FSW is the rotating tool which does the main action of welding. Here a heat treated threaded tool of die steel is used for the joining. Tool mainly consists three parts probe, shoulder and pin. Pin basically impinges into the joint and stirs the material at the line of joining and shoulder forge the material through the axial pressure to get the joint. Threads in pin are made in the opposite direction of the motion of the milling machine spindle i.e. in anti-clock wise direction. The tool and the tool geometry are shown in the Fig. 4 and Fig. 5.

Fig. 4 FSW Tool

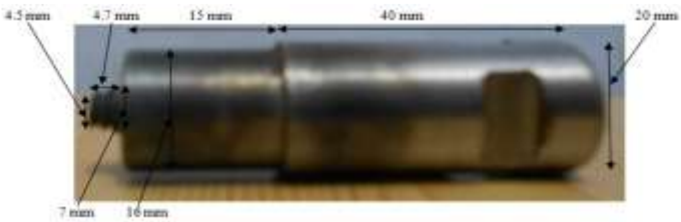

Fig. 5 Tool Geometry

IV. RESULTS AND DISCUSSIONS

Mainly UTS and Hardness of the weld joint is to be considered to get the best process parameter for FSW. Here higher the better condition is used for the parameter selection. The values of UTS and Hardness for different parameters are shown in Table 4.

In the present study, in case of FSW the joints are made at different feed/welding speeds, keeping tool rotation speed and axial force/impinging pressure kept constant. For these parameters the different values of UTS and Hardness is achieved for which are shown graphically for better understanding.

The hardness of the weld metal is measured with the help of the Rockwell hardness testing machine at B scale (HRB) and the values of the hardness in the weld region is shown in the Table 4.

Table 4 UTS and Hardness for different welding parameters

Sr. No.	Rotation speed (rpm)	Feed/Welding speed (mm/min)	Axial pressure force (kN)	UTS (MPa)	Hardness (HRB)
FSW_1	635	60	7	248	59
FSW_2	635	65	7	245	55
FSW_3	635	70	7	238	56
FSW_4	635	75	7	236	55
FSW_5	635	80	7	232	52
FSW_6	635	100	7	232	53
FSW_7	635	105	7	230	52
FSW_8	635	110	7	225	54
FSW_9	635	115	7	222	52
FSW_{10}	635	120	7	223	53

The hardness of the BM in its primary condition (when it does not weld) was 65 HRB. In FSW it is seen that the hardness of weld region decreases up to some extent and the hardness of the weld region is 59 HRB. There are the various comparative studies which show that the hardness of weld region is higher in FSW technique than the hardness of weld produced in TIG and MIG welding processes. Here it is seen that as we reduce the welding feed results of hardness changes found. It is happening because of the extra time for the stirring of the material in the weld zone and because of that very fine grain structure occurred which enhances the hardness of the weld. Graphically the hardness of different FSW welds can be shown as follows:

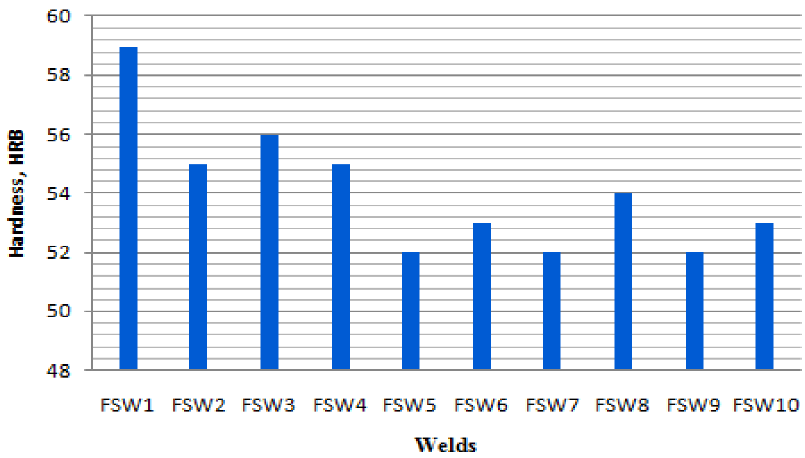

Fig. 6 Hardness Characteristics for Different FSW Welds

Aluminium alloys are strong by virtue of precipitation hardening through ageing. It is seen that the BM possesses higher strength than the welded joint material, and this is because in BM silicon and magnesium alloying elements present. In BM these two elements basically combine and because precipitation reaction makes a strengthening precipitate of Mg_2Si. These precipitates are distributed very fine and uniformly in the aluminium matrix and because of that BM material shows the higher values of strength and hardness [6].

It is found that for low feed rate the material get mixed very finely as compare to the higher feed of the tool. This fine mixing of material gets happen because of the too much time of stirring. This becomes the main reason towards the higher yields and ultimate tensile strengths. Here in this study it is found that the ultimate tensile strength of the weld is increasing constantly as the welding feed speed decreasing. Graphically this thing can be understand more easily.

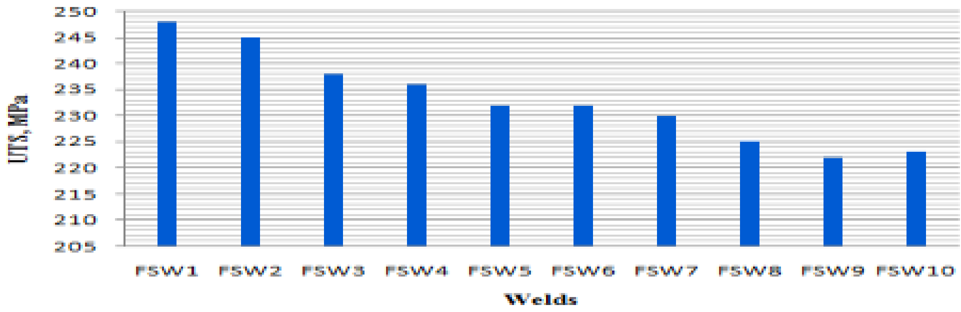

Fig. 7 UTS for Different FSW Welds

During tensile testing it was observed that all the specimens were break down/failed at the weld region which means that the weld region possesses lower resistance to load than that the other regions, hence the joint properties is controlled by weld region chemical composition and microstructure**.**Based on the experimental study done by Kulekci*et al.* (2010) [7] FSW process carried out at a constant tool rotation of 1600 rpm and welding speed of 200mm/min and observed that the average tensile strength of the base metal is 290MPa and for FSW is 270MPa, it seen 7% lower than base metal and stirring effect of the FSW process gives a finer microstructure to the weld.

V. CONCLUSION

After the welding by FSW at different welding feed speeds keeping rotation speed and axial force constant, mechanical properties of welds have been tested and following conclusions can be drawn that for welding AA6061 at low rpm milling machine the appropriate process parameters may be 635 rpm as tool rotation speed, 7 kN as axial force and 60 mm/min as tool feed, as the better welding mechanical properties are found by these parameters on low rpm milling FSW machine.

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