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Friction Stir Welding Process Parameters of Aluminium Alloys 6xxx Series: A literature Survey

Raj Kumar[1], Vedant Singh[2]
[1]M.Tech Student, Department of Mechanical Engineering, Abhilashi University, Mandi, HP, INDIA
[2]Assistant Professor, Department of Mechanical Engineering, Abhilashi University, Mandi, HP, INDIA

ABSTRACT

Friction stir welding is a new concept in welding processes, there are many areas, in which this process needs investigation to optimize and make it commercially liable. Aluminium-Magnesium alloys and their welded joints show mechanical properties. Aluminium alloys shows good mechanical properties when welded with Friction Stir welding. So in order to obtain these desired mechanical properties, certain welding process parameters are to be studied. Here, a literature survey has been carried out for the friction stir welding and its process parameters for Aluminium alloys of 6xxx series.

Keywords-- Aluminium alloys, Friction Stir Welding, Process parameters and Mechanical Properties

I. INTRODUCTION

1.1 Aluminium and its alloys

Aluminium has been a commercial metal for just a little over 100 years, it is now ranked as second to steel in both worldwide quantity and expenditure and is clearly the most important of the nonferrous metals. It has achieved importance in virtually all segments of the world economy, consumer durables and mechanical equipment.

A number of unique and attractive properties account for the engineering significance of aluminium. These include its workability, light weight, corrosion resistance, and good electrical and thermal conductivity. Aluminium has a specific gravity of about one-third the weight of steel for an equivalent volume. Cost comparisons are often made on the basis of cost per pound, where aluminium is at a distinct disadvantage, but there are a number of applications where the more appropriate comparison would be based on cost per unit volume. Since a pound of aluminium would produce three times as many same-size parts as a pound of steel, the cost difference becomes markedly less.

Probably the most serious weakness of aluminium from an engineering viewpoint is its relatively low modulus of elasticity, about one-third that of steel. Under identical loadings, an aluminium component will deflect three times as much as a steel component of the same design. Since the modulus of elasticity cannot be significantly altered by alloying or heat treatment, it is usually necessary to provide stiffness through design features such as ribs or corrugations. These can be incorporated with relative ease, however, because aluminium adapts quite readily to the full spectrum of fabrication processes.

Aluminium alloys are having significant properties as light weight, high strength, linear expansion, good machining, formability, good conductivity etc.

1.2 Classification of aluminium alloys

The aluminium alloys can be divided into two major groups based on the method of fabrication..

- Wrought aluminium alloys
- Cast aluminium alloys

Wrought aluminium alloys

The Wrought aluminium alloys can be further divided into two basic types: those that achieve strength by solid-solution strengthening and cold working and those that are strengthened by heat treatment (age hardening). Table 1 lists some of the common wrought aluminium alloys in each family, using the standard four-digit designation system for aluminium. The first digit indicates the major alloy group. The second digit is usually zero. Nonzero numbers are used to indicate some modification to the original alloy. The last two digits simply indicate the particular alloy within the family.

Table 1 Classification of Wrought Al alloys

Major Alloying Element	Series Designation
Aluminium, 99.00% and greater	1xxx
Copper	2xxx
Manganese	3xxx

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Silicon	4xxx
Magnesium	5xxx
Zinc	6xxx
Other element	8xxx

Cast aluminium alloys

Although its low melting temperature tends to make it suitable for casting, pure aluminium is seldom cast. Its substantial shrinkage and susceptibility to hot cracking cause considerable difficulty, and scrap is high. By adding small amounts of alloying elements, however, very suitable casting characteristics are obtained and strength is increased. Aluminium alloys are cast in considerable quantity, and many of the most popular alloys contain enough silicon to produce the eutectic reaction, giving the materials low melting points, good fluidity, and high as-cast strength. Copper, zinc and magnesium are known as most popular alloy additions that involves the formation of age-hardening precipitates. Table 2 lists some of the commercial aluminium cast alloys and employs the designation system of the Aluminium Association.

Table 2 Classification of Cast Al alloys

Major Alloying Element	**Series Designation**
Aluminium, 99.00% and greater	1xx.x
Copper	2xx.x
Silicon with Cu and/or Mg	3xx.x
Silicon	4xx.x
Magnesium	5xx.x
Zinc	7xx.x
Tin	8xx.x

1.3 6xxx Series Aluminum Alloys

For the manufacturing of 6xxx series alloys magnesium and silicon are used as main constituent. When these are used as a major alloying element, the result is a moderate-to-high-strength, work-hardenable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8% Mg being equal to 1.25% Mn, and it can be added in considerably higher quantities. The 6xxx series alloys possess good welding properties. However, certain limitations should be placed on the amount of cold work and the safe operating temperatures permissible for the higher-magnesium alloys to avoid susceptibility to stress-corrosion cracking. Uses include architectural, ornamental and decorative trim; cans and can ends; household appliances; streetlight standards; boats and ships, cryogenic tanks; crane parts and automotive structures.

1.4 Welding of aluminum alloys

The most widely used joining methods for aluminium alloys are gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), variable polarity plasma arc (VPPA) and electron beam welding (EBW). These processes allow as to obtain optimum mechanical properties with minimum distortion due to the high heat intensities provided by these sources. GMAW is employed for joining relatively thicker sections and GTAW for thin sheets. A lot of problems are associated with these welding techniques for different alloys of aluminum. This led to the development of solid state welding process like Friction Stir Welding technique, an upgraded version of the friction welding processes. This process has many advantages associated with it and can weld many aluminum alloys such as 6xxx series which are difficult to weld by fusion welding processes.

II. RELATED APPROACH

2.1 Friction Stir Welding

Friction stir welding (FSW) was invented and experimentally proven by Thomas in 1991 and a team at The Welding Institute , Cambridge, UK. The technique is derived from the conventional friction welding. This process is mainly suited for aluminium **[Dawes et al., 1996],** and generally for large pieces, which cannot be easily heat treated to recover temper characteristics. The process is most suitable for components, which are flat and long like plates and sheets, but can also be adapted for pipes and hollow sections **[Mandal 2005].** The welds are produced by the combined action of frictional heating and mechanical deformation due to a rotating tool.Fig 1.1 shows schematic Friction stir welding.

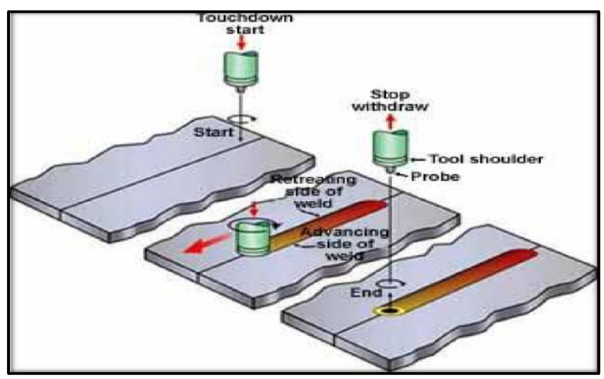

Figure 1.1 Friction Stir Welding

It is a process in which a cylindrical-shouldered tool with a profiled threaded/unthreaded probe is rotated at a constant speed and fed at a constant traverse rate into the joint line between two pieces of sheet or plate material, which are butted together. Here the length of nib is slightly less than the weld depth required and it is required that the tool shoulder should be in intimate contact with the work surface. The nib is then moved against the work, or vice versa. Frictional heat is generated between the wear-resistant welding tool shoulder and nib and the base material of the work pieces. This heat, along with the heat generated by the mechanical mixing process and the

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adiabatic heat within the material, causes the stirred materials to soften without reaching the melting point, cites a solid-state process, Which allows the traversing of the tool along the weld line in a plasticized tubular shaft of metal. As the pin is moved in the direction of welding, the leading face of the pin, assisted by a special pin profile, forces plasticized material to the back of the pin while applying a substantial forging force to consolidate the weld metal. This welding of the material is facilitated by severe plastic deformation in the solid state, which involves dynamic recrystallization of the base material.

2.2 Process Parameters of Friction Stir Welding

While the general principles of the effect of process variables on the friction stir welding process have much in common with other welding processes, there are many factors which can affect output response. The main process variables in friction stir welding are listed as follows:

- Tool rotational speed
- Welding speed
- Shoulder diameter
- Pin diameter and profile
- Axial force
- Tilt angle
- Work piece material
- Plunge Depth

All these variables act to determine the outcome of the welding process. The main interest in studying the effect of the process variables lies in understanding the effect of the process on joint properties.

III. LITERATURE SURVEY

Thomas [1997] focused on this study the relatively new joining technology, friction stir welding (FSW). Friction stir welding could be used to join most aluminium alloys and surface oxide presents no difficulty to the process. On the basis of this study it was recommend that number of lightweight materials suitable for the automotive, rail, marine and aerospace transportation industries can be fabricated by FSW.

Ouyang et al., [2002] performed the study over the same and dissimilar alloys using the tool grade steel tool over the following configuration 6061-6061 & 6061-2024 alloy with the parameters 151-914 rpm & 57-330 mm/min with threaded tool. The vortex like structure formed is attributed as the result of the stirring action of the threaded tool, extrusion and tool traverse featured by the concentric rings for 6061-6061 Al and alternative lamellae by 6061-2024 Al. The nugget region is classified into the three regions Mechanically Mixed Region featured by the dispersed particles of different alloy constituents, stirring induced plastic flow region (SPFR) characterized by vortex-like lamellae of two Al-alloys and the unmixed region consisting of fine equiaxed grains of the 6061-Al alloy. The material in the vicinity of the tool is softened and behaves like the liquid of the high viscosity. At high welding speed like 229 mm/min faster return flow is required to satisfy the return flow takes a shortcut back to the surface instead of reaching the root and results in the two or more rotating cells.

Liu et al., [2003] investigated the tensile properties and fracture locations in FSW of AA6060-T6 alloy of dimensions 30 mm X 80 mm X 5 mm. An HSS tool with diameter of shoulder and pin as 15, 6 mm respectively with pin length of 4.7mm and 3° tilt angle. Rotation speed, weld speed and revolutionary pitch were taken as weld parameters in ranges 1000-1500 rpm, 100-1000 mm/min, 0.07-1.00 mm/r respectively. They concluded that for 0.53 mm/r of pitch, 1500 rpm, welding speed of 800 mm/min, the maximum UTS of joint is about 77% of base metal.

Minton et al., [2006] demonstrated conventional milling machine has been capable of performing FSW and producing reasonable welds using a relatively stout tool to join 6.3 mm thick 6082-T6 aluminium. Lesser quality welds were produced when joining 4.6 mm thick 6082- T6 aluminium. Further work is required establish if the welds in the 4.6 mm can be improved, by enhancing the tool design, while ensuring the tool is sufficiently robust to survive the process. The methodology is tested by producing same thickness welds of 6.3 mm and 4.6 mm 6082-T6 aluminium sheets. The results from micro-hardness profiles across the tool shoulder diameter are presented in conjunction with tensile test results.

Balasubramanian [2008] studied the process parameters optimization for friction stir welding of RDE-40 aluminium alloy using the Taguchi technique. The Taguchi parametric design and optimization approach was used to evaluate the effect of strength of friction stir welded RDE- 40 aluminium alloy. The results of these studies indicated that the rotational speed, welding speed and axial force were the significant parameters in deciding the tensile strength of the joint. The predicted optimal value of tensile strength of friction stir welded RDE-40 aluminium alloy was 303 MPa.

Elangovan et al., [2009] developed a mathematical model to predict tensile strength of the friction stir welded AA6061 aluminium alloy by incorporating FSW process parameters. Four factors, five levels central composite design has been used to minimize number of experimental conditions. Response surface method (RSM) has been used to develop the model. The joints fabricated using square pin profiled tool with a rotational speed of 1200 rpm, welding speed of 1.25 mm/s and axial force of 7 kN exhibited superior tensile properties compared to other joints.

Karthikeyan et al., [2011] conducted a study on relationship between process parameters and mechanical properties of friction stir processed AA6063-T6 aluminum alloy with 200 mm X 50 mm X 10 mm as work piece

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dimensions. The tool used was HSS with cylindrical shoulder and right hand threaded pin. Shoulder and pin diameter were 18 mm and 6 mm respectively with 5.7 mm pin length, rotational speed of 800, 1000, 1400, 1600 rpm is taken for each of 22.2, 40.2 and 75 mm/min tool feed for each of 8, 10 and 12 kN of axial force were weld parameters. They concluded that the weld had refined and homogenized grain structure in microstructure. The great mechanical properties can be got with feed of 40.2 mm/min, rotational speed in range of 1200- 1400 rpm and axial force of 10 kN. Defect free welds with good microstructure was obtained by these properties. The maximum increase in UTS is 46.5%, ductility is 133%, micro hardness is 33.4% of the parent metal. Specimens in which welding is done at 8 kN feed rate yielded process defects

Jayaraman et al., [2014] studied the surface roughness (R_a), roundness (Ø) and material removal rate (MRR) of AA6063 T6 These were measured under different cutting conditions for diverse combinations of machining parameters. From this analysis, it is revealed that feed rate, depth of cut are prominent factors which affect the turning of aluminium alloy. The feed rate (P = 57.365%) is the most influencing factor in determining the multiple performance characteristics or grey relational grade (GRG) followed by depth of cut (P = 25.11%) and cutting speed (P =17.35%). The best multiple performance characteristics was obtained with uncoated carbide insert when turning aluminium alloy with the lower cutting speed of 119.22 m/min, lower feed rate of 0.05 mm/rev and medium depth of cut of 0.15 mm with the estimated multiple performance characteristics (GRG) of 0.8084. The experimental value of GRG for this combination of parameters is 0.7717. The value of multiple performance characteristics obtained from confirmation experiment is within the 95% confidence interval of the predicted optimum condition.

Elanchezhian et al.,[2014] studied Taguchi method to obtain optimal condition for Friction Stir Welding of AA8011-6062 aluminium composite and concluded results with ANOVA experiment. It was obtained that maximum tensile strength of 153MPa was exhibited by the FSW joints fabricated with the optimized parameters of 1400 r/min rotational speed, 75mm/min welding speed, 7 kN axial force, shoulder diameter of 15.54mm, pin diameter of 5.13mm, and tool material hardness of 600 HV. Tool rotational speed of 1200 r.p.m, welding speed of 100 mm/min and Axial force of 5 KN is the optimum machining condition to get a good impact strength. The optimum machining condition to get high tensile strength is tool rotation speed of 1400 r.p.m, welding speed of 75 mm/min and axial force of 125.73 kN. Welding speed has negligible influence on Tensile strength.

Bayazid et al.,[2015] showed, the effect of rotational speed, travel speed and plates positions on strength of dissimilar 6063-7075 joint which was investigated by using Taguchi method and ANOVA analysis. Results of S/N analysis indicates that the optimal condition for dissimilar 6063-7075 joint is achieved when values of rotational speed, travel speed and plates' positions were 1600 rpm, 120 mm/min and AS-7075 respectively. In such condition, tensile strength of joint was 143.59 MPa. The ANOVA analysis indicated that effectiveness of rotational speed, travel speed and plates' position parameters on tensile strength of joint were 59%, 30% and 7% respectively.

Fu et al., [2015] performed FSW over dissimilar 6061-T6aluminum alloy to AZ31B magnesium alloy using 800 rpm & 50 mm/min by H13 Quenched & Tempered to 50 HRC tool. The placing of Mg on the advancing side lead to removal of defects and more homogeneous mixing. A small cavity was observed when the tool offset is zero in Mg-Al configuration. In Mg-Al configuration when the tool was given offset towards Al the area defects increased. When the tool speed was varied (with tool offset +0.3mm) from 600 to 800 rpm & traverse speed was in the range 30 to 60 mm/min, sound weld with no defect is obtained. The Energy Dispersive X-ray analysis of IMCs of specimen obtained at 700 rpm, 60 mm/min with Mg on AS and offset +0.3 mm revealed the presence of the Al, Mg content, the variation of contents suggested that layers of $Al_{12}Mg_{17}$& Al_3Mg_2 were present. Welding condition was affected by two factors heat input and level of heat input to materials. The heat input was varied from rotation rate and welding speed.

Abraham et al., [2016] said that AA6063 Quartz AMCs can be effectively developed using FSP. The microstructure, micro hardness and sliding wear behaviour were studied using optical, scanning and transmission electron microscopy and concluded that quartz particles increased the micro hardness of the composite The micro hardness was measured to be 62 HV at 0 vol.% and 135 HV at 18 vol.%. Quartz particles enhanced the wear resistance of the composite. The wear rate decreased as the volume fraction of quartz particles was increased. The wear rate was found to be 583 × 10^{-5} mm^3/m at 0 vol.% and 258 × 10^{-5} mm^3/m at 18 vol.% quartz particles influenced the wear mode in addition to the morphology of the wear debris. The increased volume fraction of quartz particles changed the wear mode from adhesion to abrasive. The wear debris transformed from thin plate at 0 vol.% at to spherical shape at 18 vol.%.

Sharma et al.,[2016] Friction stir welding of circular butt weld joint between Aluminium alloy AA6061 and Magnesium alloy AZ31 was studied and studied as AL 6061 and Mg AZ31 can be welded using FSW by proper selection of tool pin profile and welding parameters. Different tool designs and specifications affect

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the appearance as well as properties of welded joint. As the tool rotational speed of 1200 rpm and welding speed of 10 mm/min were found to be the most influential parameters, affecting mechanical properties of circular butt weld joint between AA6061 and AZ31 when welded by using cylindrical threaded pin tool of HCHCr material.

IV. SUMMARY OF LITERATURE SURVEY

Sr. No	Author Name and Year	Investigated Problem
1	Thomas [1997]	Friction stir welding for the Transportation in industries
2	Ouyang et al., [2002]	Material flows during friction stir welding (FSW) of the same and dissimilar aluminium alloy
3	Liu et al., [2003]	Mechanical properties of friction stir welded joints of 6060 - H24 aluminium alloy
4	Minton et al., [2006]	Utilization of engineering workshop equipment for friction stir welding
5	Balasubramanian [2008]	Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique
6	Elangovan et al. [2009]	Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy
7	Karthikeyan et al. [2011]	Relationship between Process Parameters and Mechanical Properties of Friction Stir Processed AA6063-T6 Aluminum Alloy
8	Jayaraman et al. [2014]	Multi-response Optimization of Machining Parameters of Turning AA6063 T6 Aluminium Alloy using Grey Relational Analysis in Taguchi Method
9	Elanchezhian et al.,[2014]	Parameter Optimization of Friction Stir Welding Of AA8011-6062 Using Mathematical Method
10	Bayazid et al.,[2015]	Investigation of Friction Stir Welding Parameters of 6063-7075 Aluminum Alloys by Taguchi Method
11	Fu et al., [2015]	Friction stir welding process of dissimilar metals of 6061-T6 aluminum alloy to AZ31B magnesium alloy
12	Abraham et al., [2016]	Development of quartz particulate reinforced AA6063 aluminum matrix composites via friction stir processing
13	Sharma et al.,[2016]	Experimental Analysis of Friction Stir Welding of Dissimilar Alloys AA6061 and Mg AZ31 Using Circular Butt Joint Geometry

V. CONCLUSION

After a comprehensive study of the existing literature, a number of gaps have been observed in friction stir welding of aluminium alloy 6xxx series.

- Most of the researchers have investigated influence of a limited number of process parameters on the friction stir welding of aluminium alloy 6xxx series.
- Literature review reveals that the researchers have carried out most of the work on varying one parameter at a time and no consideration has been given to interaction effect of two or more parameters.
- Conventional methods of experimentation with multiple parameters and responses are line consuming, costly and are even inadequate for prediction of' mechanical properties. Little effort has been devoted to investigate the combined effect of process parameters on mechanical properties.

So, a comprehensive study can be planned to investigate combined, main and interaction effects of tool rotational speed, welding speed, and plunge depth and other paraments on mechanical properties of friction stir welded aluminium alloy 6xxx series. The effect of process parameters on mechanical properties of friction stir welded aluminum alloy 6xxx series can be easily predicted by using various techniques of design of Experiments for examples Taguchi Method etc.

REFERENCES

[1] Dawes, C.J. and Thomas, W.M. (1996) "Friction stir process Welds Aluminum alloys", Welding Technology, Vol. 4, pp. 41-45

[2] Thomas W.M, Nicholas E.D., (1997) "Friction stir welding for the Transportation in industries." Material & Design, Vol. 18(4-6), pp. 269-273.

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[3] Mandal N. R. (2005) "Aluminium Welding", Narosa Publishing House, Second edition,New Delhi.
[4] Ouyang J. H., Kovacevic R., (2002) "Material flows during friction stir welding (FSW) of the same and dissimilar aluminium alloy", Material Engineering Performance, vol. 11(1), pp. 51-63.
[5] Liu, Huijie, Fuji, H. (2003) "Mechanical properties of friction stir welded joints of 6060- H24 aluminium alloy", Science and technology of welding and joining, Vol.8, pp.50- 54.
[6] Minton, T. and Mynors, D. J. (2006) "Utilization of engineering workshop equipment for friction stir welding", Journals of Materials processing Technology, Vol.177, pp.336- 339.
[7] Lakshminarayanan A. K., Balasubramanian V., (2008) "Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique", Transactions of Nonferrous Metals Society of China, Vol. 18, pp. 548-554.
[8] Elangovan, K., Balasubramanian, V. and Babu, S. (2009) "Predicting tensile strength of friction stir welded AA6061 aluminium alloy joints by a mathematical model", Materials and Design", Vol.30, pp.188-193.
[9] L Karthikeyan and V.S. Senthil Kumar, (2011) "Relationship between Process Parameters and Mechanical Properties of Friction Stir Processed AA6063-T6 Aluminum Alloy", Materials and Design, Vol. 32, pp. 3085-3091
[10] P. Jayaraman, L. Mahesh kumar (2014) **"**Multi-response Optimization of Machining Parameters of Turning AA6063 T6 Aluminium Alloy using Grey Relational Analysis in Taguchi Method**"**Procedia Engineering, Volume 97, Pages 197-204
[11] C.Elanchezhian, B. Vijaya Ramnath, P. Venkatesan, S. Sathish, T. Vignesh, R.V. Siddharth, B. Vinay, K. Gopinath(2014) "Parameter Optimization of Friction Stir Welding Of AA8011-6062 Using Mathematical Method" Procedia Engineering, Volume 97, Pages 775-782.
[12] S.M. Bayazid, H. Farhangi, A. Ghahramani(2015) "Investigation of Friction Stir Welding Parameters of 6063-7075 Aluminum Alloys by Taguchi Method". Procedia Materials Science, Volume 11, , Pages 6-11.
[13] Fu B., Guoliang Qin, Fei Li, Xiangmeng Meng, Jianzhong Zhang, Chuansong Wu. (2015) "Friction stir welding process of dissimilar metals of 6061-T6 aluminum alloy to AZ31B magnesium alloy", Journal of Materials Processing Technology, vol. 218, pp 38-47.
[14] S. Joyson Abraham, S. Chandra Rao Madane, I. Dinaharan, L. John Baruch (2016)"Development of quartz particulate reinforced AA6063 aluminum matrix composites via friction stir processing".Journal of Asian Ceramic Societies, Volume 4, Issue 4, December 2016, Pages 381-389
[15] Heena K. Sharma, Kamlesh Bhatt, Krunal Shah, Unnati Joshi (2016) " Experimental Analysis of Friction Stir Welding of Dissimilar Alloys AA6061 and Mg AZ31 Using Circular Butt Joint Geometry" ,Procedia Technology, Volume 23, Pages 566-572.

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