A Survey of the Parameters of the Friction Stir Welding Process of Aluminum Alloys 6xxx Series

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ABSTRACT

Friction stir welding is a modern innovation in the welding processes technology, there are several ways in which this technology has to be investigated in order to refine and make it economically responsible. Aluminum alloys have strong mechanical properties when they are welded by using the Friction Stir welding. Therefore, certain parameters of the welding process need to be examined to achieve the required mechanical properties. In this project, a literature survey has been performed about the friction stir welding process and its parameters for 6xxx series aluminum alloys.

Key words:
Friction stir welding, welding process, aluminum alloys, mechanical properties

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INTRODUCTION

Aluminum has been used as a commercial metal for 100 years ago. Currently, it is rated second in terms of both global quantity and investment and is obviously the most valuable non-ferrous metal. It has gained prominence in nearly all sectors of the global economy, market sustainability in addition to mechanical machinery.

The engineering importance of aluminum accounts for a variety of special and desirable properties including the light weight, workability, resistance to corrosion as well as both good thermal and electrical conductivity. Furthermore, the specific gravity of Aluminum has is around one-third of the steel weight for an equal length. Cost comparisons are mostly made based on the cost per pound, where aluminum is at a distinct drawback in this case, although there are a variety of uses where a more accurate comparison will be depending on the cost per unit amount. Because a pound of aluminum can generate three times as many pieces of the same size as a steel pound, the cost differential is significantly less.

Perhaps the most significant drawback of aluminum from an engineering viewpoint is it has comparatively poor elasticity modulus, around one-third of the steel's elasticity modulus. Under the same loading conditions, the aluminum element is deflected three times more than the steel element of the same model. Although the elasticity modulus could not be considerably changed by the heat treatment or alloy, the stiffness is typically required to be provided by the design features like corrugations and ribs. These could be integrated relatively easily, though, as aluminum adapts very well to the broad range of production processes. Aluminum alloys have important properties such as good machining, high strength, good conductivity, lightweight, formability, in addition to linear expansion.

This study aims to provide a survey of the Parameters of the Friction Stir Welding Process of Aluminum Alloys 6xxx Series, this can be achieved through the following objectives:

- To study the classifications of aluminum alloys.
- To study 6xxx Series Aluminum Alloys
- To study the Welding process of aluminum alloys.
- To analyze different studies related to the study topic.

METHODOLOGY

Classification of aluminum alloys: Aluminum alloys could be classified into two main classes depending on the process of manufacture, which are wrought aluminum alloys as well as Cast aluminum alloys.

Wrought aluminum alloys: The Wrought aluminum alloys are divided into two main types; the first type involves aluminum alloys that achieve strength by improving the solid solution and cold working in addition to those that are strengthened and improved by the heat treatment Some of the popular wrought aluminum alloys are shown in Table 1, the classification of these wrought aluminum alloys is done by using the four-digit designation system. The first digit is used to show the core category of alloys. Typically, the second digit is zero. The non - zero numbers are utilized in order to suggest an alteration of the original alloy. The last two digits clearly signify the unique alloy within the family.

Table 1: The classification of the popular Wrought alloys

Major Alloying Element	Series Designation
Aluminium, 99.00% and greater	1xxx
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Zinc	6xxx
Other element	8xxx

Cast aluminum alloys: Since it has a low melting temperature, this tends to make it ideal in casting, while the pure aluminum is rarely cast. Its significant shrinkage and vulnerability to hot cracking create tremendous difficulties, and the scrap is heavy. Even so, by incorporating small quantities of alloy elements, very desirable casting properties are obtained, and the strength is improved. Aluminum alloys are cast in a significant amount, and many of the more common alloys involve enough silicon to create a eutectic reaction, gives the materials relatively low melting points, good fluidity in addition to high as-cast strength. Zinc, magnesium, and copper are regarded as the most common additives to alloys involving the development of age-hardening particles. The most common commercial aluminum cast alloys are shown in Table 2.

Table 2: The classification of the popular 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

6xxx Series Aluminum Alloys: Silicon and Magnesium alloys are utilized as key constituents for the manufacture of the 6xxx series. When utilized as the main alloy product, the result is a moderate-to-high-strength, work-hard enable alloy. the magnesium is considerably more efficient than the manganese as a hardener, with about 0.8 % Mg becoming equal to 1.25 % Mn, which could be added in slightly higher concentrations. Alloys of the 6xxx series exhibit good welding characteristics. However, some limits must be imposed on the cold work amount and the safe working temperatures required for higher-magnesium alloys to reduce the vulnerability of the stress-corrosion cracking. Applications include ornamental, architectural, as well as artistic trim; barrels and cans; kitchen appliances; street lighting standards; vessels and aircraft, cryogenic tanks; crane parts as well as vehicle systems.

Welding of aluminum alloys: There are several joining techniques for aluminum alloys including variable polarity plasma arc (VPPA), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), as well as electron beam welding (EBW). These processes enable the optimum mechanical properties to be accomplished with minimal distortion because of the high heat intensities generated by these sources. The GMAW is used for connecting comparatively thicker parts and the GTAW is used with the thin sheets. There are a number of issues involved with these welding processes with various aluminum alloys. This contributes to the improvement of the solid-state welding method such as the Friction Stir Welding method, an improved variant of the process of friction welding. This method has several related benefits it and could weld many aluminum alloys, like the 6xxx series that are hard to weld by using fusion welding processes.

LITERATURE SURVEY

A study has been conducted by Thomas (1997) concentrated on the latest joining method including the friction stir welding (FSW). This technique can be used in order to fuse most aluminum alloys as well as surface oxide, which is not difficult to handle. Based on this study, it was obtained that the suitable amount of lightweight materials for the automobile, road, marine, aerospace, and transport industries are manufactured by using the FSW.

A study has been performed by Ouyang et al. (2002) shows the same as well as the different alloys used by the tool grade steel tool in the subsequent design 6061-6061 and 6061-2024 alloy with specifications 151-914 rpm and 57-330 mm/min with the threaded tool.

The form-like structure of the vortex is due to the stirring action of the threaded instrument, the tool, and the extrusion crosses of the concentric circles for 6061-6061 Al and the alternate lamellae for the 6061-2024 Al. The nugget zone is divided into three religions, the Mechanically Mixed Region defined by the scattered particles of various alloy components, the stirring-induced plastic flow region (SPFR) identified by the vortex-like lamellae of the two al-alloys, as well as the unmixed region composed of the fine 6061-Al alloy's grains. The substance in the instrument vicinity is softened and acts like a highly viscous liquid. At a high welding speed of about 229 mm/min, a faster return flow is needed to fulfill the return flow by taking the shortcut back to the surface rather than touching the root and resulting in two or three spinning cells.

According to Liu et al. (2003) both fracture positions and tensile properties in the FSW have been studied of AA6060-T6 alloy with dimensions 30 mm × 80 mm × 5 mm. HSS instrument with shoulder and a pin diameter equal 15, 6 mm and a pin length equals 4,7 mm as well as a tilting angle equals 3°. Welding speed, rotating speed, as well as innovative pitch, were used as welding parameters in the ranges 100-1000 mm/min, 1000-1500 rpm, and 0.07-1.00 mm/r respectively. It was concluded That the maximum joint UTS for 0.53 mm/r of the pitch, 1500 rpm, welding velocity of 800 mm/min equals 77% of the base metal.

A has been conducted by Minton et al. (2006) proven that the traditional milling machine was able to conduct FSW and achieving fair welds utilizing a comparatively stout method for joining 6.3 mm thickness 6082-T6 aluminum. Lower quality welds were created while welding 4.6 mm thickness 6082-T6 aluminum. Additional analysis is needed to determine whether welds of 4.6 mm could be enhanced by improving the tool design whilst ensuring that the tool is stable to withstand the process. The used methodology is tested by manufacturing 6082-T6 aluminum sheets with the same thickness welds of 6.3 mm as well as 4.6 mm. The findings of the micro hardness profiles around the diameter of the tool shoulder are identified in accordance with the results of the tensile test.

Balasubramanian (2008) examined the method parameters optimization of the friction stir welding of RDE40 aluminum alloy by utilizing the Taguchi method. Both the parametric design, as well as the optimization method of the Taguchi, was utilized in order to test the impact of the welded RDE-40 aluminum friction stirring strength. The findings of these experiments showed that the rotating speed, welding speed as well as axial force are considered important parameters of the joint tensile strength's estimation. The welded RDE-40 aluminum alloy expected optimum tensile strength was 303 MPa.

Elangovan et al. (2009) established a mathematical model in order to estimate the welded aluminum alloy AA6061 frictional stir tensile strength by adding FSW process characteristics. Four considerations, five layers of core composite architecture have been utilized in order to reduce the experimental conditions' number. The Response Surface Method (RSM) was utilized in order to build the model. The joints manufactured utilizing a square pin profiled device with a rotational velocity equals 1200 rpm, a welding velocity equals 1,25 mm/s as well as an axial force equal to 7 kN had excellent tensile properties relative to the other joints.

A study has been conducted by Karthikeyan et al. (2011) in order to study the relationship between the process parameters as well as the friction stir processed AA6063-T6 mechanical properties with work piece dimensions 200 mm × 50 mm × 10 mm. The utilized tool in this study was HSS with right hand threaded pin with diameter equals 6 mm, as well as the cylindrical shoulder with diameter, equals 18 mm. Moreover, the length of the pin was 5.7 mm, the rotational velocity of 800, 1000, 1400, and 1600 rpm selected for 22.2, 40.2, and 75 mm/min tool feed for axial forces of 8, 10, and 12 kN. It was found that the weld had a homogenized as well as refined microstructure grain composition. The high mechanical properties could be accomplished with a feed equals 40.2 mm/min, a rotational speed ranges between 1200 and 1400 rpm as well as an axial force equals 10 kN. These properties have been obtained from defect-free welds with a strong microstructure. The overall rise in the UTS equals 46.5 %, ductility equals 133 %, and micro-hardness equals 33.4 % of parent metal. The specimens wherein welding is carried out at a feed rate equals 8 kN generated process defects.

According to Jayaraman et al. (2014) the roundness (Ø), surface roughness (Ra), as well as material removal rate (MRR) of the AA6063 T6 have been studied. These were evaluated under varying cutting conditions of various machining parameters combinations. The results of this study have been shown that the cutting depth and the rate feed are important factors that affect the aluminum alloy transformation. Also, the results show that the feed rate of 57.365% is the most influential factor in the assessment of various output characteristics or Gray Relational Grade (GRG) accompanied by cutting depth of 25.11 % as well as cutting velocity of 17.35 %. When transforming aluminum alloy with lower cutting velocity equals 119.22 m/min, a medium cutting depth equals 0.15 mm and a reduced feed rate equals 0.05 mm/rev and with an estimated multiple performance characteristics (GRG) equals 0.8084, the optimal multiple performance characteristics were achieved with unbleached carbide inserts. For such a combination of the parameter, the obtained experimental value of GRG equals 0.7717. Inside the 95 % confidence interval of the expected optimum state, the value of multiple output features derived from the validation experiment is 95%.

Elanchezhian et al. (2014) taguchi tested the method in order to achieve an optimum condition of AA8011-6062 aluminium compound for Friction Stir Welding and also reported findings with the ANOVA test. FSW joints manufactured with standardized parameters of rotational velocity equals 1400 r/min, welding velocity equals 75mm/min, axial force equals 7 kN, shoulder diameter equals 15.54mm, pin diameter equals 5.13mm in addition to tool material stiffness equals 600 HV were found to have an ultimate tensile strength of 153 MPa. The optimal machining conditions for strong impact strength is when the tool rotational velocity of 1200 $r.p.m$, a welding velocity equals 100 mm/min, as well as an axial force, equals 5 KN. Rotational velocity equals 1400 $r.p.m$, welding speeds equals 75 mm/min, as well as axial force, equals 125.73 kN are the optimal machining conditions with the high tensile strength. The welding velocity has a marginal effect on the tensile strength.

Bayazid et al. (2015), the strength of the contrast joint 6063-7075 were examined through the use of ANOVA analysis and the Tagus method in which the effect of speed of travel, rotational speed, and platelet position were revealed. The outcomes of the S/N study show that when the rotation speed values, plate locations, and speed of traveling were 1,600rpm, AS-7075 as well as 120 mm/min respectively, the appropriate state of the 6063-7075 divergent joints has been achieved. The joint tensile strength in such a situation has been 143.59 MPa. A study by ANOVA found which the effectiveness of variables of rotational speed, motion velocity as well as plate location on tensile strength of the joint has been 59 percent, 30 percent, and 7 percent, respectively.

According to Fu et al. (2015), FSW conducted utilizing 800 rpm and 50 mm/min by H13 Quenched and Tempered to 50 HRC instrument over different 6061-T6aluminum alloy with AZ31B magnesium alloy. The placement of Mg on the advanced side leads to defect elimination as well as a more homogeneous mixing. A small cavity has been found in the Mg-Al specification when the instrument offset equals zero. The region defects expanded in the Mg-Al specification when the device has been offset to the Al. When the velocity of the tool ranged between 600 and 800 rpm and the traverse velocity ranged between 30 and 60 mm/min, sound weld without defect is received. The analysis of energy Dispersive X-ray of the collected specimen IMCs at 60 mm/min, 700 rpm with Mg on AS, as well as +0.3 mm offset showed the Al presence, Mg material, indicating that Al12Mg17 and Al3Mg2 layers were found in the variety of content. The performance of welding was influenced by two variables: heat input in addition to the heat input level of materials. The heat input was different from the welding velocity and the rate of rotation.

Table 3: Summery of related work

Study number	Name of Author and Year	Studied Problem
1	Karthikeyan et al. (2011)	The relationship between the mechanical Characteristics as well as the Friction Stir AA6063-T6 Aluminum Alloy Process Parameters.
2	Elanchezhian et al. (2014)	Variable Friction Stir Welding Enhancement of AA8011-6062 Utilizing Mathematical Approach.
3	Fu et al. (2015)	the process of friction stirs welding of 6061-T6 aluminum alloy different metals with AZ31B magnesium alloy
4	Sharma et al. (2016)	Experimental study of the Friction Stir Welding process of different Mg AZ31 as well as Alloys AA6061 utilizing Circular Butt Joint Configuration.
5	Jayaraman et al. (2014)	The multi-response Improvement of Turning Machining Parameters AA6063 T6 Aluminum Alloy utilizing Taguchi Process Gray Relational Analysis.
6	Bayazid et al. (2015)	The 6063-7075 Aluminum Alloys Friction Stir Welding Parameters' evaluation by using the Taguchi Process.
7	Thomas)1997)	The use of friction stirs welding in the transportation.
8	Balasubramanian)2008)	Improvement of process parameters of the RDE-40 aluminum alloy friction stir welding utilizing the Taguchi method.
9	Ouyang et al. (2002)	The flows of material through friction stir welding (FSW) of the different and same aluminum alloy.
10	Elangovan et al. (2009)	Impacts of both the tool pin profile as well as axial force on the configuration of the AA6061 aluminum alloy friction stir manufacturing zone.
11	Liu et al. (2003)	The properties of the 6060 - H24 aluminum alloy friction stir welded joints.
12	Abraham et al. (2016)	improvement through friction stir processing of the quartz particulate strengthened AA6063 aluminum matrix composites
13	Minton et al. (2006)	The use of Friction Stir Welding Manufacturing Workshop Apparatus

Abraham et al. (2016), said that by using FSP, Quartz AMCs AA6063 could be produced effectively. Using scanning, photography, as well as transmission electron microscopy, the micro hardness, microstructure, as well as sliding wear actions have been researched and found that the particles of quartz improved the composite's micro hardness. At 0 vol. percent as well as 135 HV at 18 vol. percent, the hardness of micro has been estimated to be 62 HV. The particles of quartz increased the composite's wear resistance. The rate of wear has been reduced as the particle volume fraction of quartz has been increased. In addition to the wear debris morphology, the rate of wear has been observed to be 583 * 10−5 mm3/m about 0 vol. percent as well as 258 * 10−5 mm3/m about 18 vol. percent of the particles of quartz that are affected by the wear mode. The raised particle volume fraction of quartz modified the wear phase from binding to brusque. The debris of wear shifted at 0 vol. percent from a thin plate to a circular shape at 18 vol. percent.

Sharma et al. (2016) Circular butt weld joint friction stir welding between magnesium alloy AZ31 and aluminum alloy AA6061 has been tested and studied as Mg AZ31 and AL 6061 could be welded using FSW through correctly choosing the profile and parameters of the tool pin. The welded joint characteristics, as well as the appearance, have been influenced by various device designs as well as requirements. The most important variables were chosen to become the rotational speed of the device equal to1200 rpm as well as the speed welding equal to 10 mm/min, impacting the mechanical characteristics of the round butt-welding junction between AZ31 and AA6061 when welded using HCHCr product cylinders threaded pin equipment.

RESULTS AND DISCUSSION

Friction Stir Welding

Thomas invented the friction stir welding (FSW) which he practically demonstrated in 1991 with a team located at the Welding Institute, in the United Kingdom. The friction stir welding (FSW) technique has been derived from conventional friction welding. This technique is used directly for aluminum material, as indicated by Dawes et al., 1996. It is generally suitable for large elements that are characterized by their inability to be easily heat-treated in order to restore their mix ability. As for the components that are characterized by their length and are flat in shape, an example of these components plates, this technique is very suitable for it, in addition to the ability of this technique to adapt for hollow sections and tubes (Mandal, 2005). The combined effect of mechanical deformation and frictional heating induced through a revolving instrument creates welds. Figure 1 shows the friction Stir welding schematic diagram.

This technique performs the process of rotating a tool consisting of cylindrical shoulders in conjunction with the rotation of a non-straight threaded probe, the rotation takes place at a constant speed and at the same time between the plate material or the two pieces of the plate to be welded are fed at the constant rate at the link line where the two pieces are connected to each other. The nib length here has been marginally lower than the necessary depth of welding as well as the shoulder of the tool has to be in direct connection with the layer of work. The nib would then be pushed into the movement, or inversely. Between both the shoulder of the durable tool of welding as well as its tooth and even the working piece's base material, heat of frictional has been produced. Side by side with the heat produced through the mechanical mixing operation as well as the continuous heat inside of the component, this heat, based on the solid-state operation, softens the mixed materials despite touching the melting points allowing the device to move along a welding direction in the metal's annealed tubular column.

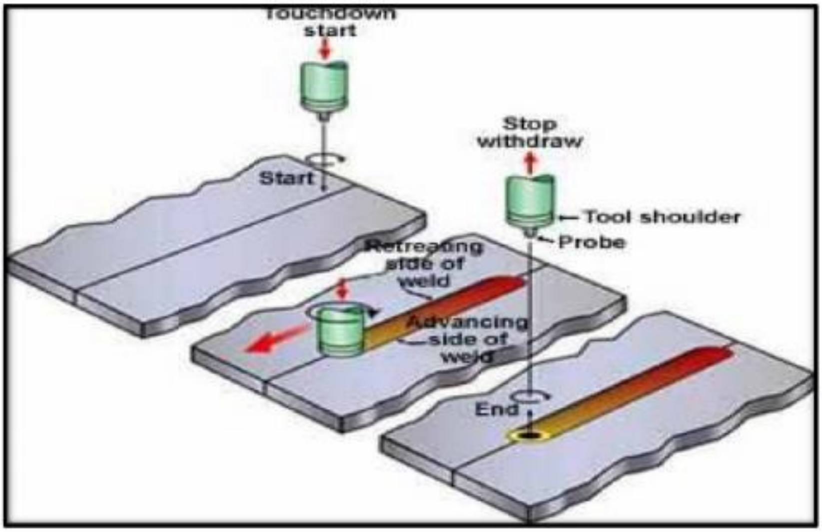

Figure 1: The friction Stir welding schematic diagram

The pin front face, supported through a particular pin profile, pushes material pf plastic to the pin back while implementation a large welding force in order to strengthen the welding metal as when the pin has been moved in the welding direction. Extreme plastic displacement throughout the solid phase that requires complex recrystallization of the material of base, enables such welding of the material.

The Parameters of the Friction Stir Welding Process

Although there are several factors that could influence performance reaction, the basic concepts of the impact of processing parameters on the process of friction stir welding have been something popular with other welding methods. In friction stir welding, the key process parameters are described as follows:

- The diameter of the pin and its profile
- Axial force
- The diameter of the shoulder
- The rotational speed of the tool
- The angle of tilt
- The speed of welding
- Plunge Depth
- The material of the work piece

CONCLUSION

After a full study of the available literature on the subject, it was observed that in stir friction welding there were many gaps for the aluminum alloy 6xxx series.

- The effect of a small range of process variables on friction stir welding of the 6xxx aluminum alloy chain has been studied by many researchers.

- The literature review shows that much of the analysis on changing one variable at a time has been carried out through the researchers as well as little attention has been given in order to the connection influence of two or more variables.
- Expensive, Line-consuming, and even insufficient for prediction of material characteristics have been traditional approach of experimentation with several variables as well as reactions. The combined impact of the process variable on mechanical characteristics has been investigated with little effort.

It is possible to fully plan for the comprehensive study in order to evaluate the main, combined, and reactive effects of each of the welding speed, the speed of rotation of the tool, the depth of welded and other variables and factors that affect the mechanical properties of aluminum alloys that have been welded by friction 6xxx. It is easy to forecast the impact of process variables on the friction stir welded aluminum alloy 6xxx series mechanical characteristics through using different experimental design methods like Taguchi Method etc.

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