International Journal of Scientific Research in Mechanical and Materials Engineering
© 2022 IJSRMME | ISSN : 2457-0435

Friction Stir Welding of Cast Aluminium Alloy (A356) : A Review

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Article Info
Volume 6, Issue 1
Page Number : 11-18

Publication Issue :
November-December-2021

Article History
Accepted : 01 Feb 2022
Published : 10 Feb 2022

ABSTRACT

Cast aluminium alloy used in automotive and aerospace applications are increasing due to their light weight and castability. It is necessary to weld aluminium castings to themselves and various applications. These alloys are not easily weldable by conventional fusion welding techniques because the quality of the welded joint is deteriorated due to the presence of porosity, hot cracking and distortion. Friction Stir Welding (FSW) process is an emerging solid state joining process in which the material that is welded, does not melt. FSW creates the weld joint without bulk melting. Therefore, welds made by FSW to have much improved mechanical properties than corresponding fusion welds. In this paper, Joints were fabricated using different levels of tool rotation speed, welding speed and axial force. Specimens were prepared from the welded joints. Tensile test, hardness measurement analyses on specimens were carried out and to predict the tensile strength of friction stir welding joints, was develop FSW process parameters using statistical tools such as design of experiments (DOE) and analysis of Variance (ANOVA).

Keywords : Cast Aluminium Alloy, Friction Stir Welding, Tensile test, Hardness, Design of experiment

I. INTRODUCTION

Welding is one of the most important joining processes in any manufacturing industry. It is widespread and versatile technique for joining two pieces of the same kind of metal. It is done by melting the joining faces of work pieces and adding filler material to form a pool of molten material at that region which cools to become strong joint. Many different energy sources like gas flame, electric arc, laser, electron beam and ultra sound etc. are used as the energy sources for welding.

In solid welding techniques, the joining of surfaces is occurring at a thermoplastic state developed by the heat energy due to friction between joining surfaces or with any external tool. FSW is important type of solid welding techniques. Now it is used extensively in aerospace and shipbuilding industries, where high strength and light weight material like aluminium and steel alloys are commonly used for structural fabrication. FSW utilizes a rotating tool progressing along a joint to heat and forge metals. After the non-consumable rotating tool is applied to the base metals, a central pin, or probe, makes contact with the parts to be joined, followed by the shoulder. As the tool rotates and progresses down the joint, it heats and plasticizes the materials where it makes contact, sweeping them behind it and eliminating the interface. The process is shown in Figure 1.1. Various process parameters which determine the strength characteristics of friction stir welded joints are geometry of the tool, tool material, tool traversing speed, rotation of the spindle, orientation of spindle, axial load on the tool, tool tilt angle, position of the tool, tool heat input, cooling rate, plates thickness and material of the specimen. (E.Massoni et al., 2002). Many research publications are available on almost all these aspects. Major publications include design of experiment based optimization of process parameters, numerical study on heat generation while FSW process, dissimilar metal joining (Elatharasan and Kumar, 2012), influence of tool geometry etc. For the present study mechanical and microstructural characteristics of cast aluminium alloy (A356) material using friction stir weld joint have been investigated. As per AWS, it is a solid state joining process in which bonding is produced at temperature lower than the melting point of the base materials. There are different types of friction welding techniques. Some of them are linear friction welding, inertia friction welding and rotary friction welding etc.

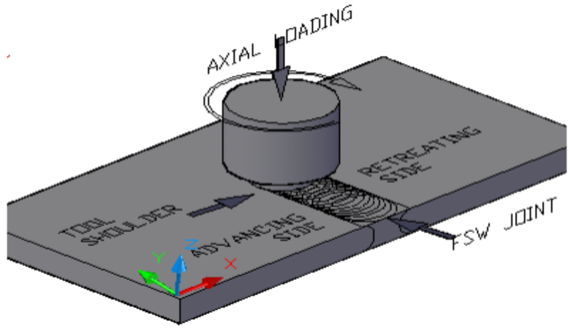

Fig.1.1: Friction Stir Welding

Due to their properties include low density, appearance, strength, fabricability and corrosion resistance Cast aluminium alloys are the most versatile of all common foundry alloys and generally have the highest castability ratings. The important characteristics which include high fluidity, low melting point. A356 (Al-Si-Mg) aluminium alloy has excellent castability and good mechanical properties that can be varied by heat treatment. Its use is widespread in the automotive industries for alloy wheels, cylinder heads and blocks and in many other industries such as chemical, marine and electrical.

Need for Welding of Cast Alloys: For a variety of reasons it is necessary to weld aluminium castings to themselves because for needed to weld may be

- A damaged casting
- Joining multiple castings
- Build-up of a casting as part of the manufacturing process.
- Joining of aluminium to other metals such as copper and steel.

Cast aluminium alloy are used widely number of constructions produced from Al-Si alloys is continually increasing like rims of complicated shape with different wall thicknesses. It was already known that the joint between cast Al alloys has a potential for expanding the usage of economic casting in airframe and missile applications.

Problems during welding of Cast Alloy: Cast alloys are not easily weldable by fusion welding processes. Common defects that are encountered during the welding of these alloys, which will reduce the strength of the weldments, are as follows:

Porosity: Porosity arises from the gas dissolved in the molten weld metal, which becomes trapped during solidification, forming bubbles in the solidified weld metal. Hydrogen has low solubility in the solid but high solubility in molten aluminum, which is a major problem and leads to defect.

Hot Cracking: Hot cracking is high temperature cracking mechanism and is a function of how metal alloy systems solidify. It is caused due to difference in the melting points of the different alloying elements added to the pure metal. In the aluminum alloys, the alloying elements form a range of eutectics with varying freezing points.

Loss of strength in Heat affected zone (HAZ): Heat affected zone experiences one or more cycles of heating and cooling, the properties of the weldment are different from those of the unaffected base metal.

Grain coarsening: Weld fusion zones exhibit coarse grains because of the prevailing thermal conditions during weld metal solidification. This results in weld mechanical properties and poor resistance to hot cracking.

Scope of FSW: The usage of cast aluminium alloy in automotive and aerospace applications is ever increasing due to their light weight and castability. It is already known that the joint between cast aluminium alloys has lot of potentials for expanding the usage of economic casting in aircraft and automotive applications. These alloys are not easily weldable by conventional fusion welding techniques because the quality of the welded joint is deteriorated due to the presence of porosity, hot cracking and distortion. Friction Stir Welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. FSW creates the weld joint without bulk melting.

Therefore, welds made by FSW are shown to have much improved mechanical properties such as the tensile strength and the fatigue life than the corresponding fusion welds. Figure 1.2 represents examples for industrial products made by FSW techniques for marine applications. Friction welding processes are mainly used to join circular shafts and pipes. Hence it has got wide application in the area of joining carbon-steel vehicle axles and sub axles. It is also used to fabricate suspension rods, steering columns, gear box forks and engine valves. Thus it finds wide applications in automotive industries.

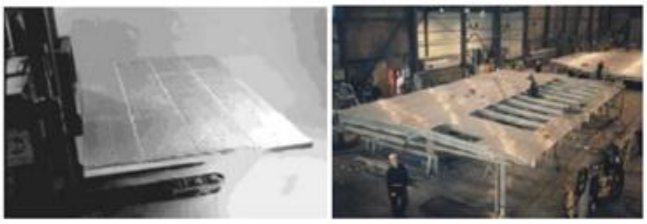

Fig.1.2: Components made of FSW techniques

Objectives: In this study, the effect of FSW process parameters on mechanical and metallurgical properties of cast Al-Si alloys. The main objective of this study is the effect of FSW process parameters (tool rotation speed, welding speed and axial force) on tensile strength, hardness and microstructure.

II. LITERATURE REVIEW

Literature review on FSW has been carried out for experimental. About twenty two papers on experimental investigation have been reviewed. In almost all the papers, the influence of process parameters, mechanical and micro structural characteristics studies are discussed. Most of the papers are related to comparative study on mechanical and microstructural characteristics of friction stir welded joints with conventionally welded joints. Some papers have focussed on the measurement of process parameters like tool rotation, tool torque and temperature distribution along longitudinal and transverse direction of friction stir welding specimen while welding both similar and dissimilar materials have been considered by various researchers for experimental investigations. **Ericsson. M et al (2003)** have done experiments to evaluate the influences of welding speed on the fatigue of friction stir welded joints and compare the same with the joints from MIG and TIG welding. For the experiment two materials have been considered. They have found that welding speed had no major influence on mechanical and fatigue properties of the friction stir welded joints except some areas. **Won Bae Lee et al (2004)** investigated the FSW joints of AA6061 aluminium alloy and they observed that the hardness of the stir zone increased with the tool rotation speed. A higher tool rotation speed resulted in the lower cooling rate because stir zone reached a higher temperature. Therefore, The stir zone with larger grains and lower density of dislocations characterized higher tool rotation speed.**Cavaliere. P et al. (2006)** have conducted experiments to study the effect of welding parameters on mechanical and microstructural properties of AA6056 joints produced by FSW. Friction stir welded joints with different combinations of process parameters have been produced in this study. **Marzoli et al. (2006)** have done FSW of AA6061/Al_2O_3 alloy. The joints produced have been subjected to mechanical and micro structure characteristic studies. It is seen that tool's stirring effect has significant effect on the reinforcement particle distribution and shape. **Heurtier et al. (2006)** has done the numerical study for the mechanical and thermal modelling of FSW using AA2024-351 alloy. The model has predicted the strain rates, temperature distribution and hardness at various zones. **Watanabe et al. (2006)** have done attempt to weld aluminium alloy to steel by FSW. They have investigated the effect of pin rotation speed, the position for the pin axis to be inserted on the tensile strength and micro-structure of the joint. **Ceschini et al. (2007)** have conducted experiments to find the effect of FSW on microstructure, tensile and fatigue properties of the AA7005/Al_2O_3. Friction stir welded joints have exhibited high tensile values. The low-cycle fatigue tests evidenced a fatigue life reduction for the friction stir welded material with respect to the base composite. **Cavaliere et al. (2008)** have conducted experiments to evaluate the effect of welding parameters on mechanical and micro structural characteristics of AA6082 FSW joints. Different welded joints have been produced by them with fixed tool rotation of 1600 rpm and varying welding speed from 40 to 460 m/s. Tensile, Fatigue and micro-structure characteristics of the FSW joints have also been evaluated. **Hwang et al. (2008)** have conducted experimental study on temperature distributions within the workpiece during FSW of aluminium alloys. Welding processes have been achieved by appropriately controlling the maximum temperature during the welding process. They have also evaluated hardness and tensile strength of welded joints. **Elangovan and Balasubramanian (2008)** have conducted experiments to evaluate the influence of welding speed and tool pin profile in the formation of FSW joints in AA2219 Aluminium Alloys. Five different tool pin profiles with three different speed have been considered for the study. **Jayaraman. M et al. (2009)** have to improve strength of welded joints in fusion welding of cast Al alloys, friction stir welding technique may employed to eliminate porosity, hot cracking etc. In this study we use taguchi experimental design technique for maximizing tensile strength of friction stir welded cast aluminium alloy A319 and effect on tensile strength of FSW process parameters (tool rotation speed, welding speed and axial force) is evaluated and optimum welding condition of maximizing tensile strength is determined. **Zhang and Zhang (2009)** have conducted numerical studies on controlling process parameters in FSW. A thermo-mechanical model has been developed by them to predict the material deformation and temperature histories in FSW. It is found that welding temperature has been increased with the increase in tool rotation. It is also noticed that the input power has been increased with the increase in welding speed. **Hwang et al. (2010)** have conducted experiments to weld copper metals (C11000) using FSW. The study mainly aimed to explore the thermal history of work piece during FSW. The temperature data combined with preheat temperature records them for obtaining effective friction stir welded joints. Hardness test has been conducted on the weld to evaluate the hardness distribution in thermal-mechanical affected zones, heat affected zones and the base metal. **Elatharasan and Kumar (2012)** have conducted experiments to find out optimum welding process parameters for the dissimilar metal joining of Aluminium Alloys (AA6061-T6 and AA7075-T6). Response surface methodology has been used to predict the ultimate tensile strength and yield strength based on the main FSW process parameters like rotational speed, welding speed and axial force. **Cavaliere (2013)** have conducted experiments to evaluate the fatigue life and crack behaviour of several friction stir welded aluminium alloys. Based on their studies a multi objective optimization tool capable of all the material properties and processing parameters to the final mechanical performance of weld, have been developed. **Su. H et al. (2013)** have done experiment on FSW to facilitate simultaneous measurement of tool torque, tool traverse force and axial forces. **Yu-E-Ma et al. (2013)** have done experiments to study the effect of welding process parameters on mechanical and fatigue properties of friction stir welded 2198-T8 Aluminium Lithium Alloy joints. **Jau-Wen Lin et al. (2013)** have done experiments on FSW process to compare the mechanical and micro structure properties of pure copper welded using FSW and TIGW. Mechanical characteristic studies included tensile strength, impact resistance and hardness tests. They have found that notch tensile strength, notch strength ratio for the friction welded joints are higher. **Durso. G et al. (2014)** have done experiment to study the fatigue crack growth in the welding nugget of FSW joints of 6060 aluminium alloy. Tensile tests, metallographic analyses and Vickers tests have also been carried out to evaluate the mechanical properties of the joints as a function of process parameters. **Singh. V et al. (2017)** have to optimize and make it aluminium –magnesium alloys welded joints using friction stir welding and to obtain the desired mechanical properties, certain welding process parameters.**Pandey. Kr. Pradeep and Singh. V et al. (2018)** In this paper, we study a review of friction stir welding process and the effect of process parameters of this welding technique on mechanical as well as microstructural behaviour of aluminium alloys.**Rajeesh J. and Balamurugan R. et al. (2019)** In this paper, we focuses on the joining aluminium alloys (AA-2014 T651) using friction stir welding technique for better mechanical properties by varying Process Parameters rotational speed, transverse speed and tool tilt at three different values for obtain higher weld strengths.**Vishvesh J. and Badheka et al. (2020)** In this study, we use friction stir welding of dissimilar aluminium alloys AA6061-T6 and AA8011-h14. The influence of the alloy and tool is study on various welding process parameter and results lead to an understanding for better weld qualities.**Senthil Kumaran S et al. (2020)** in this paper a knowledge of the process of friction stir welding of Inconel alloys that highlighting characteristics of Inconel alloys and this paper will show the results of different works concerning the behavior of tensile properties, hardness and microstructure of FSW joints of the alloy.

III. DISCUSSION AND FUTURE TRENDS

From the literature review, it is understood that friction stir welding process is an efficient process to join cast aluminium alloys. Though the reported literature on FSW of wrought aluminium alloys is enormous, the published information on FSW of cast aluminium alloys could be counted with fingers. Hence, the present investigation was carried out to understand the effect of FSW process parameters on tensile strength of welded cast aluminium alloy.

The study taken further by applying the same technique to other cast aluminium alloys. The study could be extended to join wrought aluminium alloys with cast aluminium alloys and investigated in the same way. The study could be extended for the cast Al alloys by considering other process parameters, which include tool material, tool pin profile and shoulder design. The effect of post weld heat treatment on mechanical and metallurgical properties of cast aluminium alloys could also be explored.

IV. CONCLUSION

During the friction stir welding improved mechanical properties than the corresponding fusion welds. Cast Aluminium based alloys of A356 was made by sand casting method and machined to rectangular plates. Single pass welding procedure was used to fabricate square butt joints using five levels of tool rotation speed, welding speed and axial force. The welded joints were sliced using power hacksaw and then machined to the required dimensions to prepare specimens in order to evaluate tensile strength, hardness. Hence, we achieve the formation of defect free weld region along with the fine and uniform distribution of strengthening particles under the above conditions may be responsible for attaining higher hardness and tensile strength in the respective joints.

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Cite this article as :

Akshay Patel, Lokesh Singh, Sushil Kumar Maurya, "Friction Stir Welding of Cast Aluminium Alloy (A356) : A Review",International Journal of Scientific Research in Mechanical and Materials Engineering (IJSRMME), ISSN : 2457-0435, Volume 6 Issue 1, pp. 11-18, January-February 2022. URL : https://ijsrmme.com/IJSRMME22612