Study of microstructure and mechanical properties of aa7075 aluminium alloy by using friction stir welding

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ABSTRACT
Friction Stir Welding (FSW) is a solid state joining process that utilizes the heat produced between the material and a non-consumable rotating pin to join the work pieces. The aluminum alloys are mostly used in different industrial applications such as aviation, space, railway and ship-building industries, and also in general engineering. Aluminium alloys are among the lightest structural materials. The merits of aluminum alloys are that they have a high strength-to-weight ratio and have an excellent corrosion resistance. The aim of the project is to conduct a study on the micro structural and mechanical properties of AA7075 aluminium alloy using Friction Stir Welding.
KEY WORDS: Microstructure, FSW, aluminium, hardness, machinability, tensile test.

1. INTRODUCTION

The current studies have shown the increasing importance of light-weight materials in automotive and aerospace industries. Lightweight materials are ideal for enhancing fuel efficiency in automobiles. As 75 per cent of fuel usage is related directly to weight of the vehicle. With 10 per cent weight reduction in vehicle is 6.5 to 8.5 per cent improvement can be done in fuel usage. The use of lightweight materials is a cost effective measure to reduce carbon dioxide emissions. Over the vehicle‘s lifetime around 20 kilograms of Co_2 per pound of reduction in weight can be reduced.

Uses in Automotive Industry: Lightweight materials are also used to improve design flexibility, as large rotating parts are used in automotive, where driving dynamics are a major consideration. Using light-weight materials, vehicles can carry emission control systems, safety devices and integrated electronic systems by considering the weight of the vehicle. When applied body structure, aluminum can provide a weight reduction 50 percent compared with the traditional mild steel structure.

Uses in aerospace industry: The need for lightweight materials is enormous in aerospace industries. Aluminum high volumetric energy density because of this reason it is used in space shuttle‘s solid rocket booster motor. It is very difficult to ignite accidently.

Uses in marine industry: Aluminum is widely used in ladders, railings, gratings, windows, and doors. The major of aluminum is its weight saving compared to steel.

Aluminium: Aluminium is a chemical element which is a silvery-white, soft, nonmagnetic, ductile metal. Aluminum is widely available element in the Earth‘s crust (after oxygen and silicon) and its most abundant metal. Aluminium makes up about 8% of the crust by mass, though it is less common in the mantle below. The main substrate of aluminum is bauxite.

Welding of the alloys of aluminum: Many methods are available for joining Aluminum and its alloys by any other metal, but aluminium has several chemical and physical properties when using the various joining processes.

The specific features that affect welding are its oxide characteristics, its thermal, electrical, and non-magnetic characteristics, lack of color change when heated, and wide range of mechanical properties and melting temperatures that result from alloying with other metals.

Hydrogen Solubility – in molten metal hydrogen dissolves very quickly However, primary cause of porosity in aluminum welds hydrogen has almost no solubility in solid aluminum and allows a large amount of hydrogen to be absorbed, Hydrogen that exceeds the effective solubility limit forms gas porosity, if it does not escape from the solidifying weld.

Electrical Conductivity - For arc welding, high electrical conductivity permits the use of long contact tubes guns, because resistance heating of the electrode does not occur, as is experienced with ferrous wires.

Friction stir welding: Friction stir welding (FSW) is joining metallic alloys and composites and has enormous potential for manufacturing applications. FSW is a used to create high quality joints and is capable of fabricating either butt or lap joints.

Scope and objectives: Many automotive industries demand enchanting fuel efficiency and become cost efficient. For this purpose, lightweight materials such as aluminum alloys, polymers and composites are required. Using a thin metal like aluminum in a vehicle, fuel consumption can be decreased and can increase fuel economy. By designing lightweight vehicles, emissions of carbon dioxide can also be reduced and environment can be conserved. Due to excellent machinability and recyclability of aluminum alloys, they can be machined easily and wastage of material reduces, as recycling is possible.

2. EXPERIMENTAL WORK

Experimental work in FSW: Evaluation of chemical composition and mechanical properties of base metal, Identification of process parameter - rotational speed (N), welding speed (T) and axial force (F). Optimization of process parameter. Evaluation of Metallurgical Properties – microstructure analysis. Evaluation of mechanical properties - tensile strength test and hardness test.

Valuation of base metal properties: The base metal used in this investigation was AA7075 aluminium alloy. The manufacturing industry obtained the chemical composition of base metal alloys.

Table.1.Chemical composition of AA7075 aluminium alloy

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA7075	Max 0.4	Max 0.5	1.2-2	Max 0.3	2.1-2.9	0.18-0.28	5.1-6.1	Max 0.2	Balance

ASTM E8 guidelines were followed for preparing the test samples. Tensile test was carried out using mechanical Universal Testing Machine (Make: FIE-BLUE STAR, India; Model: UNITEK-94100). The machine has a maximum capacity of 100 KN. Loading accuracy of the device as high as $\pm$ 1%. The specimen undergoes uniform deformation. Typical tensile specimen shows a reduced gauge section.

Table.2.Tensile properties of AA7075 aluminium alloy

Alloy	Ultimate Tensile Strength (Mpa)	Yield strength (Mpa)	Tensile elongation (%)	Micro Hardness (VHN)
AA7075	572	503	11	175

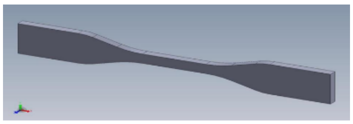

Fig.1.Model of tensile test specimen

Table.3. Dimensions of tensile specimens

Specimen	Width (mm)	Thickness (mm)	Cross section al area (mm^2)	Gauge length (mm)
T1	5.01	4.95	31.01	25
T2	6.13	4.95	30.34	25
T3	6.16	4.72	29.08	25
T4	6.17	4.72	29.12	25

Fabrication of joints: The rolled plates of aa7075 alloy were of dimensions 300 mm x 150 mm x 6 mm and were machined to dimensions of 100 mm x 50 mm x 5 mm to weld the joints. In fsw, two kinds of rotating tools (cylindrical threaded and cylindrical) of high carbon steel are designed and hardened to manufacture the fsw joints. FSW machine with maximum load of 3 kn, the speed of 1800 rpm and power output of 10 hp was used to weld aluminium alloy plates.

Characterization: To find the various features of welded specimen a transverse cross section of the specimen was prepared.

Microstructure: Micro structural study was done using a metallurgical microscope incorporated with image analyzing software (metal vision). Specimens were etched with 1% hf solution to reveal the microstructure of the weld, base metal (bm) and haz regions.

Sem analysis: Sem analysis on the work pieces was done using a scanning electron micro-scope at a magnification of 1500x. To analyze the microstructure of the welded specimens at higher magnification. The joints welded with threaded pin profile showed better results than the cylindrical pin profile joints.

Friction Stir Welding (FSW): Wayne Thomas invented Friction Stir Welding (FSW) at TWI Ltd in 1991. FSW is a solid-state process, which helps in producing welds of high quality in difficult-to-weld materials such as aluminium, magnesium. It is the important manufacturing methods lightweight transport structures such as boats, trains and airplanes.

FSW of aluminium alloy joints: A non-consumable, rotating FSW tool with a specific geometry is plunged into and traversed through the material. The shoulder and the pin (probe) are the essential components in FSW tool during welding; the pin moves in the material, while the shoulder advances along the surface.

Effect of tool materials: Friction stir welding is done with high heat input. The tool has to be sufficiently high so that the machine doesn‘t break during the friction stir welding process.

The tool making was prepared in the following way. The tools were made using high carbon steel with hardness 60 to 62 HV. The device was manufactured by CNC (computerized numerical controller) and lathe.

Experimental work:

Design and fabrication of tool: The dimensions AA7075 plates are 100mm×50mm×5mm. The tool of pin diameter 4mm is made and it is fixed to the vertical milling machine. The chemical compositions of the aluminium alloy and the tool material are given below. The tools are case hardened at 62 HRC. Square butt joint configuration, is prepared to fabricate FSW joints. It is seen that the direction of the weld is normal to the rolling direction. A single pass welding is done on the materials to weld the joints. Tools of different profiles (cylindrical threaded and cylindrical) were used to fabricate the similar joints.

Initial hardness testing of parent material before FSW: The initial hardness testing of the parent material was done using Rockwell and Brinell hardness testing machines.

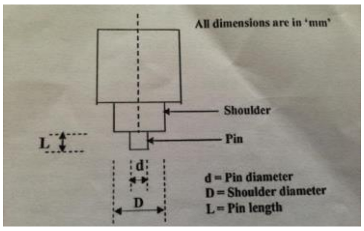

Fig.5.Schematic representation of tool profile

Fig.6.Rockwell hardness testing machine

Rockwell hardness: Indenter: steel ball; Maximum load: 100Kgf = 1000 N; Load applied: 60Kgf = 600N.

Table.4.Rockwell hardness readings

Reading	HRB	Reading	HRB
1	91	3	91
2	91	4	90

Brinell hardness: D = 10 mm hardened steel ball; Brinell microscope is used to check the impression; Maximum load = 1000 Kgf = 10,000 N; Surface area = 5.8338 mm^2; BHN = 1000 / 5.8338 = 171.414 BHN

Table.5.Brinell hardness readings

Specimen	Load (Kgf)	Penetrator	Diameter of impression, d(mm)	Surface area (mm^2)	BHN
7075	1000	10 mm ball	5.2	5.8338	171.414

Welding of work pieces: The AA7075 aluminium plates of dimensions 100mm x 50mm x 5mm were welded using a Friction Stir welding machine using two pin profiles. The specifications of machine are as follows.

Speed = 0 to 1800 rpm; Feed = 0.1 to 6mm; Axial load applied = 3KN; Semi-automatic.

The rectangular slots in the tools were cut to fit the device inside the tool holder using an align key. The work pieces were placed on the worktable and aligned according to the instrument position. The machine was set for process to be done. 6 joints were fabricated using two different pin profiles having 3 joints each.

Testing of specimens: ASTM E8 guidelines were followed for preparing the test samples. Smooth (un-notched) tensile specimens were available to evaluate transverse tensile properties of the joints such as tensile strength, joint efficiency and percentage of elongation.

Fig.7.Tensile test specimens

3. RESULTS AND DISCUSSIONS

Tensile properties: The tensile properties like tensile strength, percentage elongation and hardness of aluminum alloy welded by friction stir welding were evaluated. From each joint, two tensile samples were prepared and tested. The typical welded with threaded pin profile tool exhibited higher tensile strength, elongation and hardness value as compared with the joints welded with cylindrical tool profile. The obtained values of the tensile proper-ties are as follows.

Calculation: For T1 sample = (144.87 / 572) * 100 = 25.32%

For T2 sample = (39.21 / 572) * 100 = 6.85%

For T3 sample = (218.27 / 572) * 100 = 38.16%

For T4 sample = (48.28 / 572) * 100 = 8.44%

Table.6.Tensile properties of threaded cylindrical pin profile welded joint

Sample	Tensile strength (Mpa)	Yield stress (Mpa)	% elongation	Brinell hardness (HBW)	Rockwell hardness (HRB)	Efficiency of joint (%)
T1	144.87	134.51	1.04	173, 166, 171	94,95,95	25.32
T3	218.27	205.28	2.08	163,171,171	95,95,96	38.16

Table.7.Tensile properties of cylindrical pin profile welded joint

Sample	Tensile strength (Mpa)	Yield stress (Mpa)	% elongation	Brinell hardness (HBW)	Rockwell hardness (HRB)	Efficiency of joint (%)
T2	39.21	34.21	0.72	170,169,170	87,88,88	6.85
T4	48.28	45.28	0.88	166,169,170	85,87,86	8.44

Microstructure: Microstructure analysis was done using Metallurgical microscope at a magnification of 200X. The etchant used was 1% HF solution.

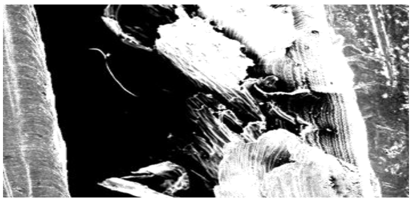

Figure.8. SEM images of cylindrical profile tool weld zone

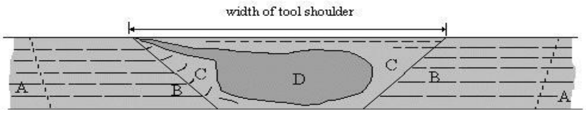

Figure.9. Schematic representation of various zones after welding

Micro hardness: Micro Vickers's hardness testing machine was employed to measure the hardness across the weld region with 1 kg load for 20 sec dwell time. The hardness was measured across the joint at mid thickness region .The hardness of base metal (un welded parent metal) is shown below. The joint fabricated by using threaded tool profile which gives greater weld zone hardness value as compared to the other. The higher hardness value is obtained in the stirred zone as compared with HAZ and TMAZ.

Sample.1. Threaded cylindrical pin profile: Base: 147,149,146; **HAZ:** 103,101,104; **Weld:** 147,149,146.

Sample.2.Cylindrical pin profile: Base: 149,148,150; **HAZ:** 105,103,102; **Weld:** 121,123,122.

SEM Analysis: SEM analysis on the work pieces was done using a Scanning Electron Micro-scope. Scanning electron microscopy (SEM) was employed to evaluate the microstructure of the welded specimens at higher magnification. The joints welded with threaded pin profile gives good results than the cylindrical pin profile joints. In this, the surface of a specimen is scanned by a beam of electrons that are reflected to form an image.

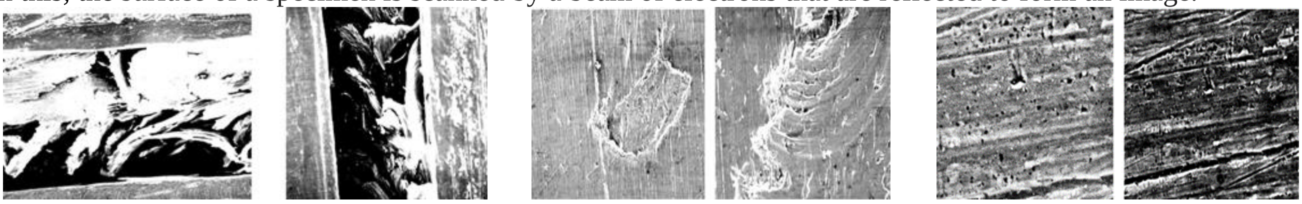

Figure.10. (a) (b) (c) SEM images of cylindrical profile tool weld zone

4. CONCLUSION

The micro structural and mechanical properties of AA7075 using Friction Stir Welding (FSW) are studied. From this study some important conclusions have been made. The hardness over the weld region was more in threaded cylindrical profile welded joint as compared to cylindrical profile. The friction stir welding process used successfully to join similar aluminum alloys AA7075. After welding the specimen by FSW by using threaded cylindrical pin profile tool, which gives good results of mechanical properties like hardness, tensile strength, percentage elongation and efficiency of joint as compared to joint welded with cylindrical pin profile tool.

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