INFLUENCE OF LIQUID NITROGEN COOLING ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF FRICTION STIR WELDED(FSW) DISSIMILAR AA5083-AA6061 ALUMINUM ALLOY JOINTS

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Abstract

In this paper, the effect of cryogenic (liquid nitrogen) cooling on grain size and influence of microstructure on mechanical properties of Friction stir welded (FSW) dissimilar Aluminium 5083 and 6061 alloys were studied due to their range of usage in naval and marine applications. However cryogenic (liquid nitrogen) coolant was employed immediately behind the FSW tool for rapid cooling to reduce the grain size and improve the mechanical properties of AA5083 and AA6061 Aluminum alloy. The welding parameters such as, welding speed, tool rotational speed and tool pin profile plays a major role in deciding the weld quality. The square tool profile generates a fairly localized deformation which results high volume of material was stirred and carried with the pin tool and also better mixing of plasticized metal. It was observed that better mechanical properties are obtained at rotational speed of 900rpm and welding speed of 31.5mm/min the fine microstructure is obtained. It was also observed that mechanical properties are enormously enriched. The experimental grain size and mechanical properties have correlated by microstructures and fracture structures.

***Keywords:*: *FSW 5083 and 6061 Aluminum Alloys, Tool Rotational Speed, Welding Speed, Mechanical Properties, Microstructure, Liquid Nitrogenetc…*

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1. INTRODUCTION

AA 5083 is a strain hardenable aluminium alloy and AA 6061 is an age hardenable aluminium alloy, but both alloys exhibit good ductility, higher strength to weight ratio and good oxidization resistance [1to3]. The dissimilar joining of these two materials leads to the combined properties of both materials, which makes this combination very much required in military applications such as light combat aircraft light combat vehicle future main battle tank, bridge layer tank, armored ambulance, submarine torpedo, etc. Aluminium materials can generally welded using fusion welded process like Gas Tungsten Arc Welding and Gas Metal Arc Welding process. However, fusion welding of dissimilar materials is a greater challenge due to the variances in chemical configuration, coefficient of thermal growth, melting point and other mechanical properties [4].In addition, the problems related to solidification such asporosity, hot cracking, etc., deteriorate the quality of weldjoint. The formation of coarse grains and large intermetallic compounds in the weld region results in poor mechanical properties. The formation of thick tenacious ceramic oxide layer on the surface restricts the welding arc to weld the aluminium alloys. This oxide layer restricts many fusion welding processes to weld the aluminium alloys. FSWis a solid state welding process developed to weld the aluminium alloys[5,6]. Fig -1 shows schematicdiagram of FSW. FSW allows the materials to be welded well below the melting temperature of the materials. Thus the formation of brittle solidified product scan be reduced and the grain boundary cracking due toliquation can be eliminated. Many metallurgical reactions between the dissimilar materials at the elevated temperature can be avoided. Thus FSW is a prospective welding process which can also join the dissimilar materials having incompatibilities [7]. The dynamic recrystallization in the dissimilar weld region is characterized by the mixing or complex intercalation of the dynamically recrystallized fine grains [8]. In FSW the temperature generation is due to rubbing of tool on work piece and the plastic deformation of the material. Tool pin profile has a remarkable effect on the rubbing and the foremost effect on the plastic deformation. The ratio of swept volume to pin volume decides the material flow [9]. The material has to swirl according to tool rotational speed and has to move with respect to tool travel speed in order to get defect free weld zone. Lot of research works on cryogenic (liquid nitrogen) cooling has been carried out throughout the world to recognize the result on microstructure and mechanical properties. Most of the literatures are focused on similar joints like Al alloy to Al alloy, Mg alloy to Mg alloy. Few investigations have been carried out on dissimilar joints. Very few investigations have been carried out on microstructural characterization and mechanical properties of FSW heat treatable (AA 6061) alloy and non-heat treatable (AA 5083) alloy.

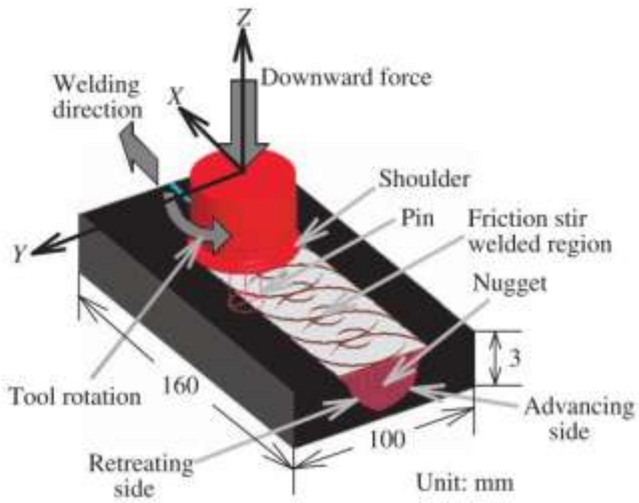

Fig -1: Schematic Drawing of Friction Stir Welding

2. LITERATURE REVIEW

Shige Matsu et. al. (2003) dealt with Joining of 5083 and 6061 aluminum alloys by friction stir welding. He states that in this process, a rotating tool travels down to the length of contacting metallic plates, and generates a highly plastically deformed zone through the associated stirring act. The localized heating zone was produced by friction, between tool shoulder and the plate top surface, as well as plastic deformation of the material in connected with the tool.

Hirata et al., (2007)wasdeveloped the connection between the microstructure of stir zone and the mechanical properties of FSW 5083 aluminium alloy. The microstructures of the stir zones consisted of fine equiaxed grains at various FSW conditions. The grain size of the stirring zone wasreduced with the reduction of friction heat flow during FSW. The results shown that micro structure and mechanical properties of the FSW 5083 Aluminum alloy joints were enhanced by the refinement of grain size of the stirring zone**.**

Mohamed Assidi et al developed a friction model for FSWprocess simulation. They conducted FSW trails on AA6061 plate with H13 tool. For different speeds of welding, the tool temperatures and forces are recorded accurately at stable welding state, for different welding speeds. The main feature of the numerical approach which was based on ALE is to exactly compute the contact and frictional surface between the plate and tool.

3. EXPERIMENTAL PROCEDURE

The base metal (BM) sheet of 5mm thick 5083-6061 Aluminum alloy was welded as a but joint with a rotating tool probe assembly by Vertical Milling Machine(VMM). Schematicdiagram of weld jointwas showed in Fig. 2. H13 tool steel is selected as tool material due to low wear resistance, great strength at elevated temperature and thermal fatigue resistance. The diameter of the shoulder was 24mm and pin 8mm used.Length of the pin was4.7mm. A constant axial force was 5 KN applied and tool onward tilt angle was2^0 for all the FSW experiments. Experiments were conducted with taper, circle tool with threaded pin and square tool pin profile on 5083-6061 Aluminum alloy with a different tool rotational speeds of 710rpm, 900rpm and 1400 rpm and also welding speeds of 60, 31.5 and 40mm/min correspondingly. Table-1 shows the welding processes parameters. A cryogenic (liquid nitrogen) is applied to the plate immediately behind the FSW tool for rapid cooling. The experiments are carried out on a VMM. The pouring of liquid nitrogen on weldment was showed in fig-3. For several testing samples were cut with required lengths as per ASTM standards.In each weld we took two tensile specimen, one impact(charpy) and one specimen for microstructure. These all arefrom the FSW nugget zone (NG) by using wire-cut Electrical discharge machining (EDM). After FSW, microstructural observations were carried out onthe cross section of nugget zone (NG) of weldments. Mechanically polished and etched with Keller's reagent of (20 ml HNO3, 3 ml HCl, 2 ml HF and 175 ml H2O) by employing optical microscope (OM). Grain size is measured as per ASTM standards. Micro-hardness tests were carried out at the cross section of NG. The tensile specimens were taken from Aluminum alloy Friction stir weldments normal to the FSW direction. The tensile test was conducted with the help of a computer controlled Universal Testing Machine (UTM. (NZ) of Aluminum alloy Friction stir weldments normal to the FSW direction, samples with a load of 5kgs and duration of 15 sec using by Vickers digital micro-hardness tester. Specimen for Impact testing was taken from NG as per ASTM standards.

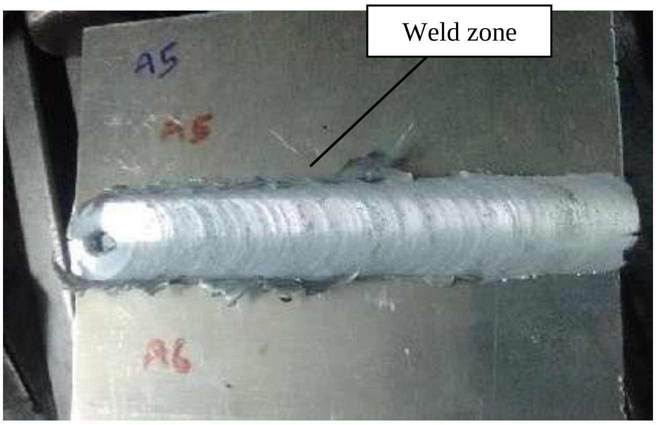

Fig -2: Schematic sketch of weld joint

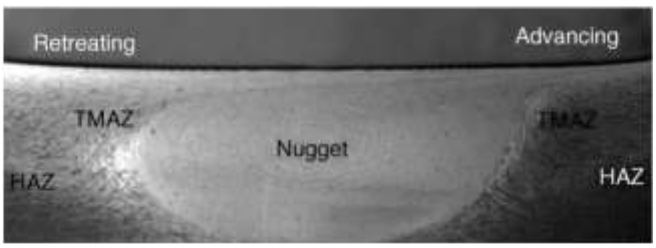

Fig-4: Macrograph of friction stir welding

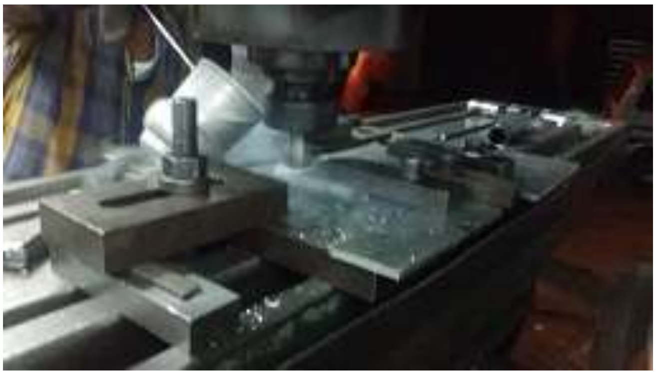

Fig-3. liquid nitrogen pouring sketch on weldment

Table -1: Welding Process Parameters

Specimen	Tool Pin Profile	Rotational Speed (rpm)	Welding Speed(mm/min)	Tilt Angle
1.	cylindrical with thread	710	60	2^0
2.	Square	900	31.5	2^0
3.	Taper with thread	1400	40	2^0

4. RESULTS AND DISCUSSIONS

4.1. Microstructure observation

Liquid nitrogen cooling was employed in process of Friction stir welding to reduce the grain size and to improve the mechanical properties of FSW welded 6061 and 5083 Aluminum alloys. It was observed that, the joints made by square toolpin profile resulted in very much smaller equiaxed grains shown in fig-4.3. compared to base material. During stirring movement of the tool which generatesgreatextent of plastic deformation and frictional heat generation amongst tool andbase material. This was due to the mechanism of Dynamic Recrystallization (DRX). The DRX usually arises in weld zone (WZ), and thus the microstructure would be sophisticated.Fig-4shows Macrograph of friction stir welded.Between WZ and BM, small portions of Thermo Mechanical Heat Affected Zone (TMAZ) and Heat Affected Zone (HAZ) remained observed. Observed Microstructures of nugget zonewas shown below.

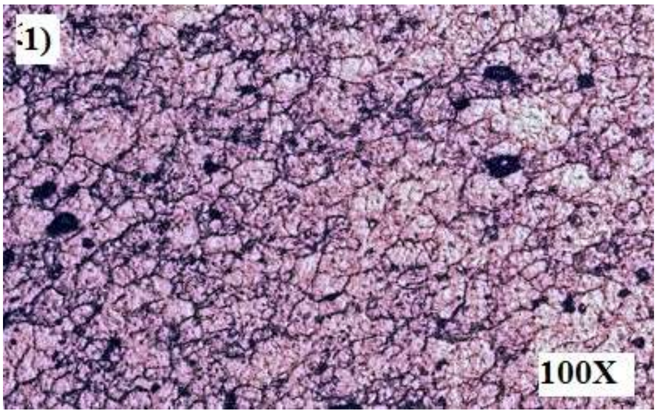

Fig -4.1: micro structure of circular with threaded probe tool at 710 rpm, 60mm/min

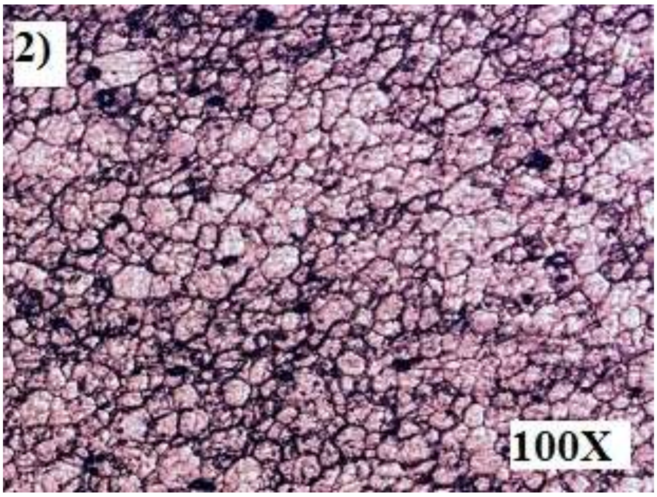

Fig -4.2: micro structure of square probe tool at 900rpm, 31.5mm/min

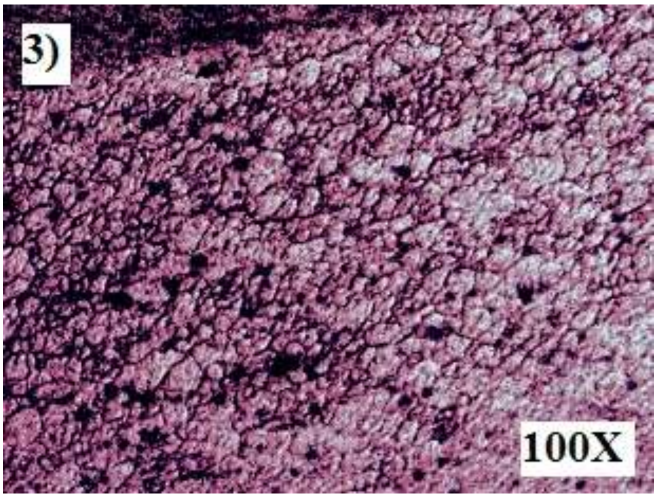

Fig -4.3: micro structure of circular with threaded probe toolat1400rpm, 40 mm/min

4.3 Mechanical Properties

The**tensile** properties like, ultimate tensile strength, percentage of elongation and yield strength of friction stir welding of AA5083 and 6061alloy joints were evaluated with different types of toolprobeshapes and existing in Table

2. The average of two samples is showed in table-2. The joints fabricated by square exhibits better tensile strength compared to base material, this may be due to the effect of grain refinement and annealing during the welding process and also effects the pulsating action. The percentage of elongation was lesser than the BM due to rise of deformation resistance which is due to the microstructure changes in the stir zone.

Table -2: Mechanical Properties

Specimen	Ultimate Tensile Strength (MPa)	% Of Elongation	Yield Strength(MPa)
1	126.16	0.6	108.13
2	**180.14**	**6.1**	**139.07**
3	127.67	1.97	107.13

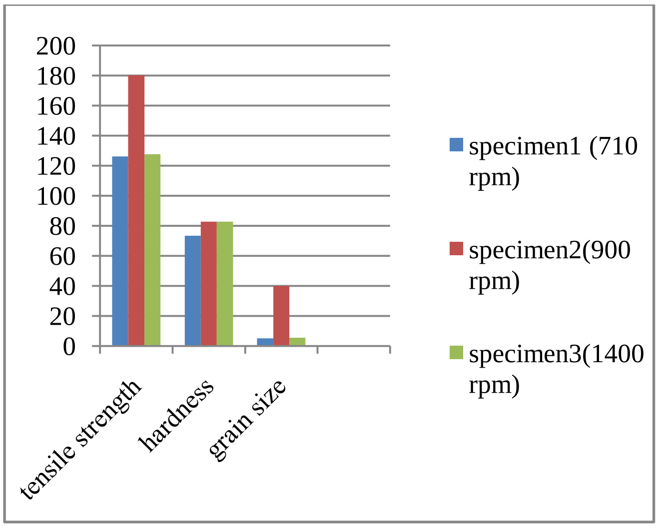

Chart -1: Mechanical properties bar chart

Table -3: Mechanical properties

Specimen	Hardness (HV)	Grain size (µm)	Impact (J)
1	73.3	5	16
2	82.8	4.2	28
3	82.7	5.5	12

For **micro hardness** using Vickers micro hardness, the hardness variation across the weld metal to base metal region are surveyed and the average valuesshown intable-3. The optimum value was obtained with square tool which was 82.8. It was more then of base metal 5083.The hardness of BM was 75Hv. The hardness of NGwas influenced by grain refinement and annealing softening in pure metals.

5. CONCLUSIONS

The effect of liquid nitrogen cooling on Grain size and Mechanical properties of FSW AA 5083and AA6061 Al alloy was successfully studied and one can drawn following conclusions:

- It was observed that, the joints made by square probe profile tool wasresulted very much smaller equated grains compared to other joints. The grain size was 4.2µm.
- However it was found that by applying liquid nitrogen cooling on dissimilar weldments thefine grain size wasattained.
- It was also concluded that as the weld speed is decreased the hardness is also improved.
- It was also observed that square pin tool welded specimen was got higher value of Vickers hardness(82.8 HV) compared to base metal 5083(75 HV).
- It was observed that when tool rotating speed 900rpm and welding speed was 31.5mm/min with square probe tool having maximum tensile strength in the order of 180.14 MPa and. Hardness 82.8HV, Impact Strength of 28J, Compared to other joints it was optimal values.

6. FUTUREWORK

In order to further understand of liquid nitrogen cooling effect on these dissimilar aluminium alloys, i will go for constant speed of 900rpm with welding speed of 40mm/min by using square pin tool and taper with threaded pin tool. Because these parameters give optimum values.

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