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Influence of Cryogenic cooling (Liquid Nitrogen) on Microstructure and Mechanical properties of Friction stir welded 2014-T6 Aluminum alloy

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Abstract

In this paper, the effect of cryogenic (liquid nitrogen) cooling on grain size and mechanical properties of Friction stir welded (FSWed) 2014 Aluminum alloy was studied. The welding parameters and tool pin profile plays a major role in deciding the weld quality. The threads on the 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. Cryogenic process (Liquid Nitrogen) was employed after Friction stir welding to reduce the grain size and to improve the mechanical properties of FSWed 2014 Aluminum alloy. It is observed that the grain size is decreased to 250 nm under cryogenic process with the liquid nitrogen by using Transmission electron microscope. It is also observed that mechanical properties are enormously improved. The observed grain size and mechanical properties have been correlated with microstructures and fracture features.

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Keywords: Friction stir welding; Cryogenic process(Liquid Nitrogen); Microstructure; Mechanical properties.

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1. Introduction

Aluminum is having a unique combined property of light weight and high machinability. This makes Aluminum as a most popular metal. It has some attractive properties are low density, good electrical conductivity, high corrosive resistance and low price. The properties as industries to use aluminum in several applications like automobile, aerospace and mineral processing industries. However, relatively low strength and uneven mechanical properties of pure aluminum and its alloy causing some troubles in engineering applications [1-2]. The mechanical properties can be enhanced by alloying copper, magnesium, and silicon etc. In fusion process, it is very difficult to join 2XXX and 7XXX series Al alloys due to solidification microstructure is very poor and porosity in the fusion zone (weld zone) [3-4].To overcome these conventional welding problems, Wayne Thomas was invented Friction Stir Welding (FSW) in 1991 at The Welding Institute (TWI) in UK. In FSW process, a rotation tool having high hardness than the base metal is used to produce sound welds. The friction is generated between the workpiece and tool shoulder and the material get often without reaching the melting point [5-6].So many researchers have mainly addressed the microstructure and mechanical properties of tool geometry and its influences on base material. A narrow literature has focused on the process parameters of FSW. The shape of the tool pin influences the flow of plasticized material and affects weld properties [7-9]. The objective of the present investigation is to study the effect of cryogenic (liquid nitrogen) cooling on microstructure and mechanical properties of the 2014 Aluminum alloy weldments.

2. Experimental Details

The base metal (BM) sheet of 4mm thick 2014 Aluminum alloy was welded by butting two plates and stirring them together with a rotating tool assembly by using vertical milling machine. Schematic sketch of weld joint and tool is shown in Fig. 1. H13 tool steel is selected as tool material due to its high strength at elevated temperature, thermal fatigue resistance and low wear resistance. The diameter of the shoulder and pin used were 24mm, 8mm respectively and length of the pin is 5.8 mm. A constant axial force is 5 KN applied and tool onward tilt angle of 1.5^0 for all the FSW experiments. It is that found to be defect free welds, the surface morphologies of the FSW joints. Based on previous work, the trial experiments were conducted with taper with threaded tool pin profile on 2014 Aluminum alloy with a tool rotation speed of 1120 rpm and welding speed of 40 mm/min. A mixture of ethanol and dry ice is applied to quench the plate immediately behind the FSW tool for rapid cooling. The experiments are carried out on a Vertical milling machine (Make HMT FM-2, 10 hp, 3000 rpm). For various testing samples were cut with required dimensions as per ASTM standards, from the FSP nugget zone by using wire-cut Electrical discharge machining (EDM). The schematic diagram of selection of samples for testing is shown in Fig.3. After FSW, microstructural observations were carried out at the cross section of NZ of weld ments normal to the FSP direction, mechanically polished and etched with Keller's reagent (2 ml HF, 3 ml HCl, 20 ml HNO_3 and 175 ml H_2O) by employing optical microscope (OM). The Scanning electron microscope (SEM) and Transmission electron microscope are also utilized for fractography analysis. Grain size is measured as per ASTM E112–13 standards.

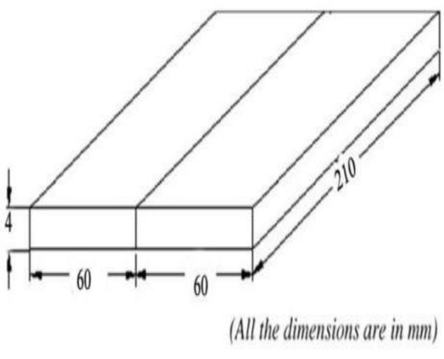

Fig.1. Schematic sketch of weld joint and tool

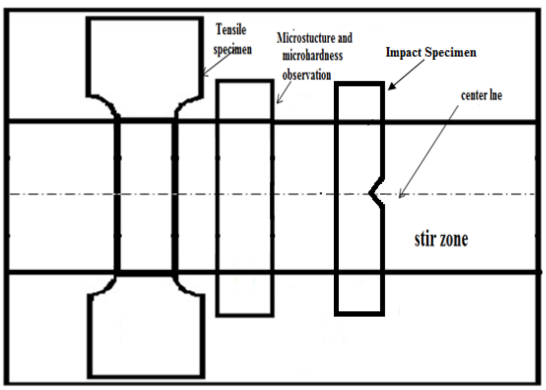

Fig.2. Schematic sketch of selection of samples for testing

The tensile specimens were taken from Aluminum alloy Friction stir weldments normal to the FSW direction and made as per ASTM: E8/E8M-011 standards by Wire cut Electrical discharge machining to the required dimensions. The schematic sketch of tensile specimen is shown in Fig.3. The tensile test was conducted with the help of a computer controlled universal testing machine at a cross head speed of 0.5 mm/min. Microhardness tests were carried out at the cross section of nugget zone (NZ) of Aluminum alloy Friction stir weldments normal to the FSW direction, samples with a load of 15 g and duration of 15 sec using a Vickers digital micro-hardness tester. The schematic sketch of microhardness survey is shown in Fig.4. Specimen for impact testing is taken in transverse to the weld direction and machined as per ASTM A370 standards.

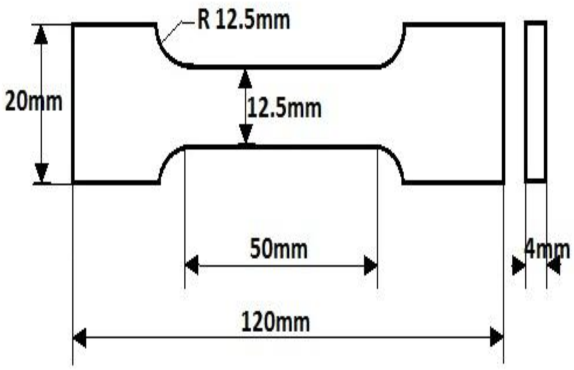

Fig.3. Schematic sketch of selection of samples for testing

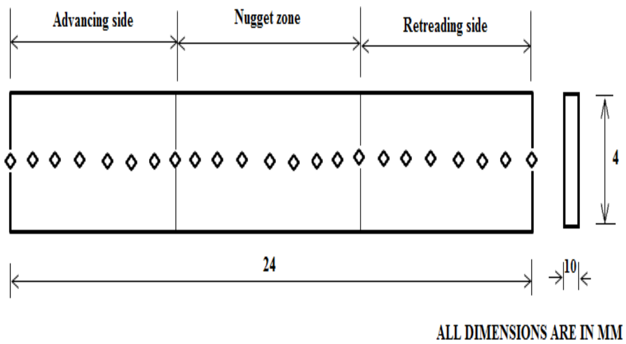

Fig.4 Schematic sketch of microhardness survey

3. Results and Explanation

3.1. Microstructural observation

Cryogenic process was employed after Friction stir welding to reduce the grain size and to improve the mechanical properties of FSWed 2014 Aluminum alloy. It is observed that the grain size is decreased to 250 nm under cryogenic process with the liquid nitrogen and TEM microstructure as shown in Fig.5.. The optical micrographs of all Aluminum alloy Friction stir weldments are shown in Fig.6. FSW is a well-known severe plastic deformation process. Stir zone was observed at the weld centre and produces finer grains. It is observed that, the joints made by Taper with threaded pin profile tool resulted in very much smaller equiaxed grains compared to base material. During stirring action of the tool which induces high amount of plastic deformation and frictional heat generation between tool and base material. This is due to the mechanism of dynamic recrystallization (DRX). The DRX usually occurs in weld zone (WZ), and thus the microstructure can be refined [10]. Between WZ and BM, small portions of thermo mechanical heat affected zone (TMAZ) and heat affected zone (HAZ) were observed. The TMAZ consists of a slightly elongated grain structure due to the annealing affect of heat and severe plastic deformation of material around the pin edge; outside of the TMAZ there is a zone (HAZ) affected only by the heat generation during the welding process [10-11] in which slightly coarse grains were observed when compared with that of the BM. The grain size in the welded joints made by taper with threaded profiled tool exhibits very finer (150nm) than base material.

3.2. Mechanical properties

The transverse tensile properties such as yield strength, ultimate tensile strength, and percentage of elongation, of friction stir welded AA2014 alloy joints were evaluated with rotational speed of 1200 rpm, and traverse speed 40 mm/min by using tater with threaded geometry tool and presented in Table 1. The joints fabricated by taper with threaded 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 is lower than that of the base metal due to the increase of deformation resistance which is due to the microstructure changes in the stir zone [12]. The hardness profiles evaluated across the weld nugget is shown in Fig.7. The hardness of the base metal is 138 Hv. The hardness of the nugget zone is influenced by annealing softening and grain refinement in pure metals [13]. The average hardness of weld zone is found to be significantly higher than that of the hardness of base metal. In Harries and Norman's work, it is suggested that the variation of the micro hardness values in the welded area and base metal is due to the difference between the microstructure of the base metal and weld zone [14]. However, in the present study the hardness of the weld zones of the taper with threaded shape profiled tool shows 165 HV which is higher than base material due to the presence of very finer grains at the weld nugget. The fracture morphology of the tensile specimens of the weld ments was studied using the SEM to understand the failure mode. The threads on the 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 [15]. The fractured surface of tensile specimens is presented in Fig.8. From the observed that the size of the dimples is smaller than those of BM, this is due to formation of extremely fine grains at the WZ produced by FSW which enhanced resistance for tensile deformation [16-17].

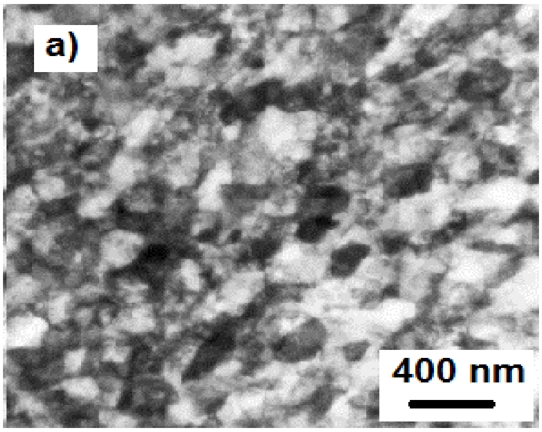

Fig.5. Microstructures of Aluminum alloy after FSW (Cryogenic cooling)

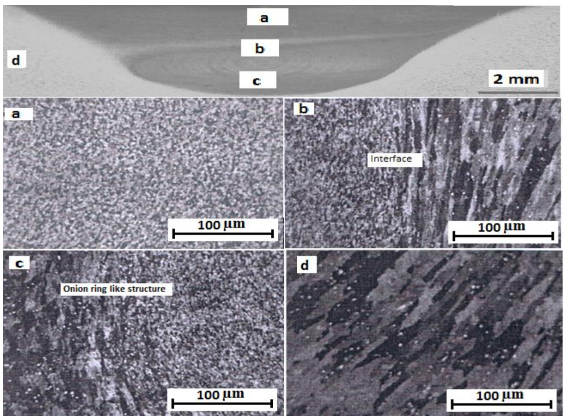

Fig.6. Microstructures of Aluminum alloy after FSW and Base material

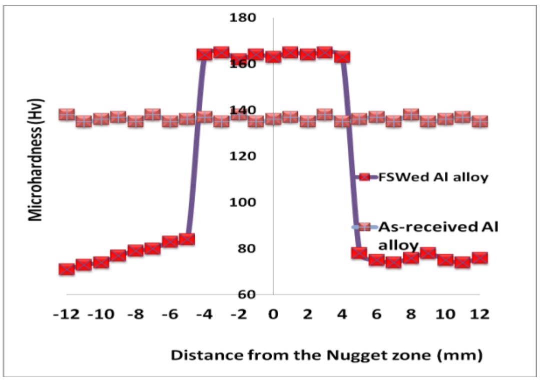

Fig.7. Hardness profiles evaluated across the weld nugget

Table 1. Mechanical properties of FSWed 2014 Al alloy

Samples	UTS (MPa)	YS(MPa)	%El	Microhardness (Hv)	Impact Strength (J)
Base Material	483	414	13	138	13
Taper with threaded	552	483	18	164	08

4. Conclusions

The effect of cryogenic cooling on Grain size and Mechanical properties of Friction Stir Welded AA 2014 was successfully studied and one can drawn following conclusions:

- It is observed that, the joints made by Taper with threaded pin profile tool resulted in very much smaller equiaxed grains compared to base material.
- It is observed that microhardness increases up to 164 Hv and which is higher than as received Aluminum alloy (138 Hv).
- It is seen that all the tensile properties of FSWed Al is increased as compared with the as-received Al alloy.
- The grain size in the welded joints made by taper with threaded profiled tool exhibits much finer (2 μm) than base material.

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