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Effect of Cryogenic Treatment on Microhardness of Friction Stir Welded Al 7050-T7451

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Abstract—*High strength Precipitation- hardening 7000 series aluminium alloy such as alloy 7050 are extensively used in aircraft industries now a days. However this class of aluminium alloy are difficult to weld by conventional fusion welding techniques due to dendritic formation in the weld. The friction stir welding (FSW) is used to join the material which is conventionally considered as un-weldable. During FSW process the material is goes intense plastic deformation at elevated temperature which results in fine and equiaxed grains. Three rotational speeds and two welding speeds are taken, and on the basis of factorial design, six different combinations of these variable are chosen in which welding is performed, different rotational speed of the tool is taken as 1000 rpm, 1150 rpm and 1300 rpm and two welding speed taken are 26 mm/min and 30 mm/min. The joint is further undergoes for Deep Cryogenic Treatment (DCT), and tested in Vickers Microhardness testing machine. The microhardness is taken in two ways: along the weld and across the weld for all joints under different parameters with and without cryogenic treatment. It is found that the maximum hardness is seen in thermal mechanical affect zone (TMAZ) of the weld bead. It is also seen that the friction stir welded joint with cryogenic treatment has more Microhardness as compare to friction stir welded joint without cryogenic treatment.*

1. INTRODUCTION

The difficulty of making high-strength, fatigue and fracture resistant welds in aerospace aluminium alloys, such as highly alloyed 2XXX and 7XXX series, has long inhibited the wide use of welding for joining aerospace structures.[1] These aluminium alloys are generally classified as non-weldable because of the poor solidification microstructure and porosity in the fusion zone. Also, the loss in mechanical properties as compared to the base material is very significant. These factors make the joining of these alloys by conventional welding processes unattractive. Some aluminium alloys can be resistance welded, but the surface preparation is expensive, with surface oxide being a major problem. [1,3] Friction stir welding (FSW) was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys. Due to the absence of parent metal melting the new Friction - Stir welding offers many advantages over the conventional welding processes.[1,4]

The basic concept of FSW is very simple; a non consumable tool with especially designed pin and shoulder is inserted into the abutting edge of sheet or plate with high rotating speed and calculated transverse speed provides the weld along the transverse direction. The heating is accomplished by friction between tool and workpiece which provides local melting of the material. The friction stir processing has been developed as a novel solid state processing to modify coarse material into nano structure.[3,5]

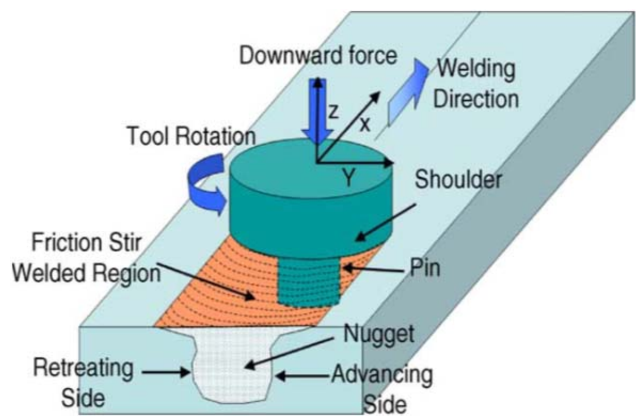

Fig. 1: Schematic diagram of friction stir welding

Cryogenic processing originally developed for aerospace applications. Cryogenic processing of metals involves the freezing of parts by lowering their temperature to that of liquid nitrogen (-320º F, -196ºC) for some period of time. Either liquid nitrogen or dry nitrogen is used from bottles or dewar flasks. It is used to modify the micro-structure of the material [11]. Cryogenic treatment promotes additional transformations in metals, alloys and other materials.

2. MATERIAL AND EXPERIMENTAL PROCEDURE

2.1 Base metal and its composition

Many metals are used in the aerospace industry out of the Al 2XXX and 7XXX series these days []. But recently it was found that the Al-Zn-Cu alloy Al705-T745 is used very extensively [12]. So Al-Zn-Cu alloy Al705-T7451 is used as a base metal in this study. The composition of the base metal is given in table 1.

Table 1. Composition of material

Component	Percentage (%) Weight
Cu	2.30
Cr	0.01
Fe	0.07
Mg	2.30
Mn	0.01
Si	0.03
Ti	0.05
Zn	6.20
Zr	0.10
Al	Rest

The microhardness hardness of base metal is found 85 HV.

2.2 Preparation of Specimen

The specimen is prepared using Wire EDM. The 6 mm thickness is selected so that the welding can be performed by single pass only.The specimen were cut and machined to obtain plates of size 78 mm long and 78 mm wide with 6 mm of thickness.

2.3 Development of FSW joint

The Specimen were arranged in square butt joint configuration and were held firmly in position, without any gap between faying surfaces of the Specimen using specially fabricated fixture. Friction stir welding was performed parallel to plate extrusion direction in single pass on vertical milling machine as shown in Fig. 2.

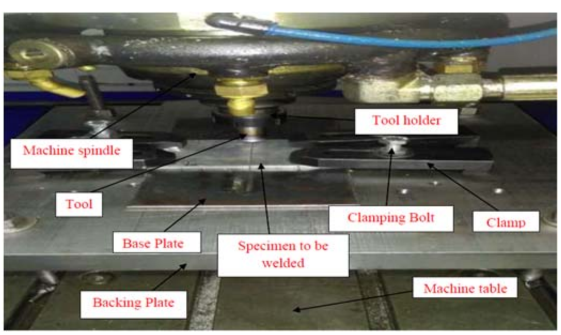

Fig. 2: Photograph of modified milling machine used for friction stir welding

The detail of the tool geometry and the welding parameter used for producing the joint is given in the table 2. Tool used for the experiment having flat shoulder and conical pin.

Table 2: Dimension used for friction stir welding

Tool Dimension in mm			
Shoulder	Pin diameter		Pin length
	Top	Bottom	
16	4	6	5.6

The tool used for welding is tapered cylindrical type tool, which is designed in solidworks 2013. The material of the tool is taken as EN-32. EN-32 is a case hardening steel with low tensile strength and is used in general engineering for the production of lightly stressed components. The material displays good weldability and machinability characteristics in the supplied condition and has a hard wearing surface. EN32 is classed as an unalloyed low carbon grade.

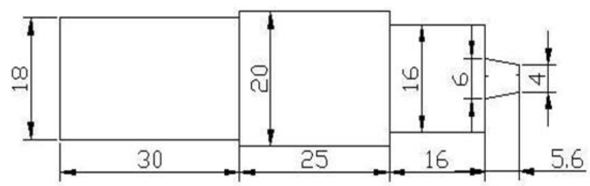

Fig. 3: Tool dimension

2.3.1 Parametric Combination

The combinations of parameter are shown below in tabular form. During the welding plunge depth and tilt angle is kept constant. The plunge depth is taken as .287mm and tilt angle is taken as 3.5˚ for all the joints.

Table 3.3 Different combination of process parameter for producing weld

Experimental runs	Welding Speed mm/s	Tool rotation RPM
1	26	1000
2	30	1000
3	30	1150
4	26	1150
5	26	1300
6	30	1300

The FSW was performed for the above said parameters combination on the 12 different specimen combination with 2 Specimen combination for each experimental run.

2.4 Cryogenic treatment

The FSW joint specimens from each parametric combinations were further undergoes through a Deep cryogenic treatment which is done using 2-8-2 cycle. The temperature of cryogenic chamber is ramp down from atmospheric temperature to -185°C in 2 hrs. The soaking period is 8 hrs. The temperature of cryogenic chamber is ramp up from -185°C atmospheric temperature in another 2 hrs. In this way 2-8-2 cycle is complete. The test rig for cryogenic treatment is shown in Fig. 3.

Fig. 4 Set-up used for Deep Cryogenic Treatment

2.5 Microhardness testing

The hardness measurement was done as per ASTM E384 Standard on aluminium alloy specimen on the Vickers microhardness tester available at SLIET Longowal (Punjab). The Vickers uses a 136^0 pyramid shaped diamond indenter that forms a square indent. The Vickers hardness number is a function of the test force divided by the surface area of the indent. For micro-hardness testing, the specimens have been prepared using standard procedure like grinding, polishing using successively fine grades of emery up to 1500 grit size. This was helpful in removing coarse and fine oxide layer as well as scratches on the surface that are to be metallographic-ally analyzed. Micro-hardness tester is used to measure micro-hardness of the specimens at a load of 100 grams, for the dwell time of 20 seconds. The average of three readings is taken as microhardness value along the cross sectional of the weld and average of five reading is taken as microhardness perpendicular to the cross section of weld.

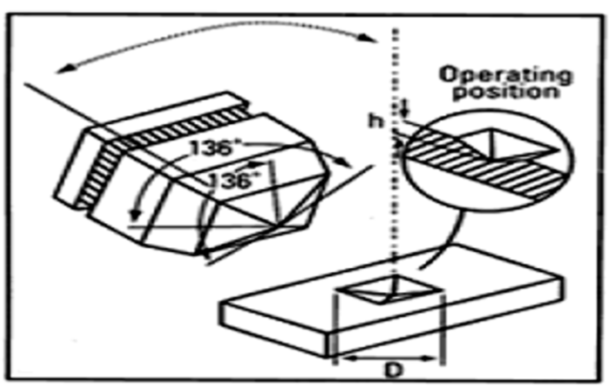

Fig. 5: Representation of the Vickers Hardness Test

3. RESULTS

Microhardness of the weld joint with and without Cryogenic across and along the weld is represented as follows:

3.1 Microhardness of FSW joint with and without cryogenic treatment along the weld

Average value of the Microhardness along the weld for the FSW joint with Cryogenic treatment is represented in the Fig. 6 for the different six experimental run specimens. It was found that the specimen number 5 (Feed: 26, RPM: 1300) has more hardness than the other specimens because of the Low feed rate and high rpm which results to have high heat input during the welding.

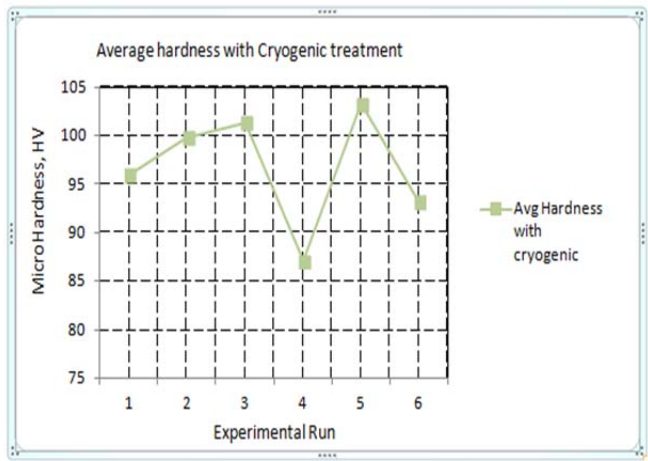

Fig. 6: Average hardness with cryogenic treatment along the weld

Average value of the Microhardness along the weld for the FSW joint without Cryogenic treatment is represented in the Fig. 7 for the different six experimental run specimens. It was found that the specimen number 5 (Feed : 26, RPM : 1300) has more hardness than the other specimens because of the Low feed rate and high rpm which results to have high heat input during the welding.

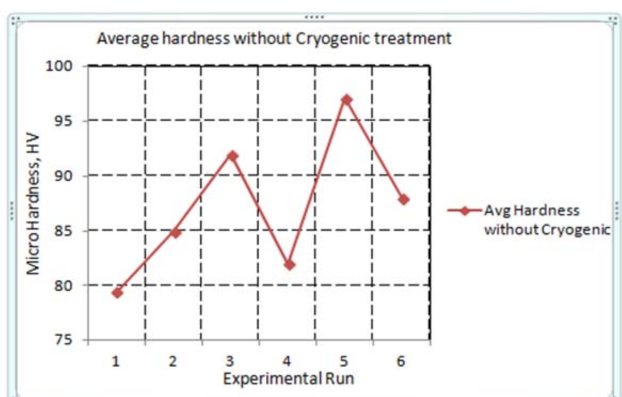

Fig. 7. Average hardness without cryogenic treatment along the weld

it is found from the literature that the microstructure consist mainly of aluminium solid solution as the matrix it had been found when the content of alloying element exceeds the solid solution solubility limit, the alloying element produce a second phase that may consist of either pure alloying ingredients or an intermetallic compounds such as $(Fe\ Cr)_3$ $SiAl_{12}$, Cu_2FeAl , Mg_2Si and many more which increases the hardness of the material after the cryogenic treatment.

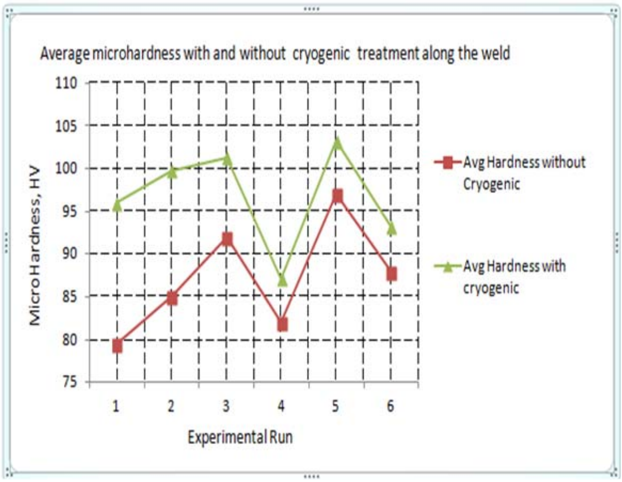

Fig. 8. Average hardness with cryogenic treatment

It is clearly seen from the graph that the hardness of cryogenic treated FSW joint is increase as compare to non treated joint. It can also be concluded from the graph that maximum hardness along the weld is obtained in fifth experimental run (Feed : 26, RPM : 1300). This indicate that more the heat input during the welding results more finer Grains in nugget zone which results in increase the hardness of the weld zone.

3.2 Microhardness of FSW joint with and without cryogenic treatment across the weld

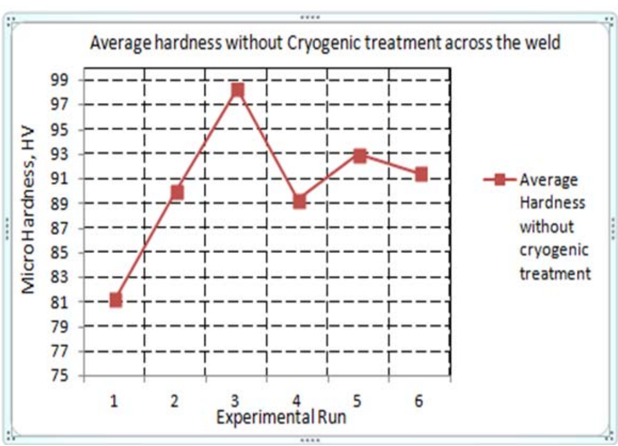

Fig. 9: Average hardness with cryogenic treatment across the weld

Average value of the Microhardness across the weld for the FSW joint without Cryogenic treatment is represented in the Fig. 8 for the different six experimental run specimens. It was found that the specimen number 3 (Feed: 26, RPM: 1150) has more hardness than the other specimens.

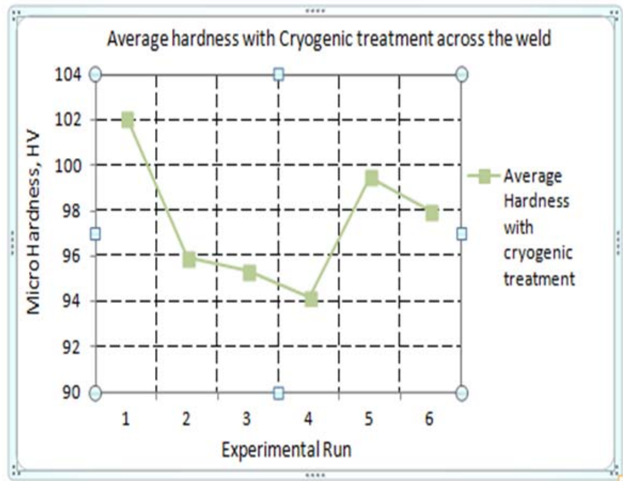

Fig. 10. Average hardness with cryogenic treatment across the weld

It is found that across the welded joint with cryogenic treatment the highest value of microhardness is found in experimental run 1 (Feed: 26, RPM: 1150) which is more than that of without cryogenic treatment. The region where maximum microhardness is comes in thermo Mechanical affected Zone (TMAZ). In this region, the FSW tool has plastically deformed the material, and the heat from the process will also have exerted some influence on the material. In the case of aluminium, it is possible to obtain significant plastic strain without recrystallization in this region, and there is generally a distinct boundary between the recrystallized zone (weld nugget) and the deformed zones of the TMAZ. This plastic strain increase increases the hardness but may decrease the other mechanical properties. [10]

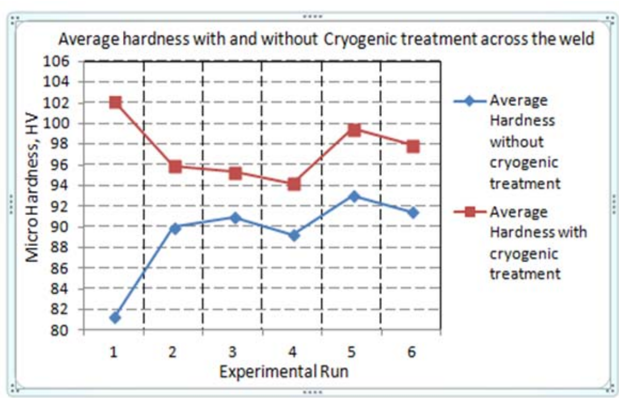

Fig. 11: Average hardness with cryogenic treatment across the weld

Fig. 11 shows that the microhardness of the FSW joint is across the weld is increases with cryogenic treatment. It is found from the study that Aluminium and zinc form eutectic containing solid solutions of 83% zinc in aluminium and 1.14% aluminium in zinc. The addition of magnesium complicates the situation with additional ternary eutectics and complex intermetallic being formed, these intermetallic providing dispersion hardening and precipitates of composition $MgZn_2$. Copper provides further precipitation hardening, forming $CuAl_2$ and an intermetallic of the copper–zinc system.[8,10]

4. CONCLUSION

From the Study following conclusion are drawn.

1. The hardness of the FSW welded joint is more than that of the base metal. It means FSW joint produce finer grains which results in increase the hardness.
2. The hardness of cryogenic treated joint is more as compare to non treated joints.
3. The cryogenic treatment increases the hardness of the joint by 5-10%

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