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Hardness Determination at Friction Stir Welded Region

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ABSTRACT

Friction Stir Welding (FSW) is a solid- state process that can be beneficially used for various Transportation, defence for construction of aircraft structures. In this study, hardness of friction stir welded Al6061-(6mm) aluminum alloys were investigated in the direction perpendicular to the friction stir welding direction. Hardness of the FSW joints were investigated from weld zone to heat affected zone and the changes in hardness compared with the parental metal. The weld parameters such as tool rotational speed of (900, 1200, 1500 rpms) by keeping traverse speed (45mm/ min) was kept constant to the samples on which hardness test is performed. Hardness of the samples were investigated by using Brinnel Hardness test machine.

Keywords*—*FSW, BHN, Hardness, Aluminum alloy 6061

I. INTRODUCTION

In recent years, demands for Aluminium alloy 6061 have steadily increased in aerospace, aircraft and automobile applications because of their excellent strength to weight ratio, good ductility, corrosion resistance and cracking resistance in adverse environment. Welding of these alloys, however, still remains a challenge. Apart from softening in the weld fusion zone and heat affected zone, hot cracking in the weld can be a serious. Thus, the solid state bonding process is highly recommended to solve these problems. FSW is an innovative solid state welding process in which the metal to be welded is not melted rather the two parts of weld joints are brought into contact and the interface is strongly forged together under the effect of heavy plastic deformation caused by the inserted rotating stir probe pin. In FSW a rotating cylindrical, shouldered tool with a profiled probe penetrates into the material until the tool shoulder contacts with the upper surface of the plates.

The parts have to be clamped on to a backing bar in a manner that prevents the abutting joint faces from being forced apart. Frictional heat is generated between the wear resistant welding tool and the material of the work pieces. This heat causes the later to soften without reaching the melting point and allows traversing of the tool along the weld line. In FSW, tool rotation rate (rpm) in clockwise or counter clockwise direction and tool traverse speed (mm/min) along the joint are the most important parameters.

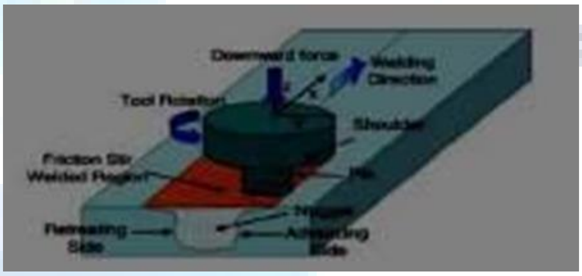

Fig 1 Schematic view of friction stir welding process

Friction Stir Welding (FSW):

Friction Stir Welding is a process in which a rotating tool is driven into a desired weld seam and traversed across the length of the seam to form a solid joint. No melting of the work piece occurs in the FSW process. The mechanics behind FSW can be complicated, and require a balance of dynamic thermal and mechanical interactions as well as flow of solid metals. In the FSW process, maintaining tool rotational speed and position of the tool head in all three axes is critical in creating a weld with consistent characteristics. Since mills used in modern manufacturing are easily capable of producing the required output energy and maintaining the tool position to a high degree of precision, FSW can easily be instituted in most manufacturing facilities.

FSW tools have a consistent design including two primary components. Each tool is comprised of a tool shoulder that maintains contact with the work piece surface during welding and a tool probe that penetrates the intended seam to the entire depth of the probe. Though tools designed for different applications may have slightly different tool probe shapes and tool shoulder shapes, all tools maintain this same two element design.

When the FSW tool is traversed along the weld seam, the tool shoulder and probe stir the material in the immediate area of the tool. In order for the FSW process to fuse the joint through the entire weld length, the FSW operation must maintain a high enough energy input per unit length travelled to drive the fusion process. In order to adequately stir the material, FSW tools must be made out of material that is significantly harder and stronger than the material to be joined to maintain rigidity. Frictional interactions from tool rotation and the plastic flow of the surrounding material result in significant generation of thermal energy, raising the total process temperature. The combination of thermal energy and stirring action induced by the FSW tool are the driving forces behind fusion in the FSW process.

When the FSW tool traverses a seam, the tool rotation causes a difference in relative velocity between both sides of the weld. The difference in relative velocity of the tool results in a directional plastic flow from one side of the tool to the other. The difference in plastic flow characteristics between the two sides causes different microstructures to form. Consequently, the two sides of the weld are described using different nomenclature. One side of the weld is denominated the advancing side, while the other side is termed the retreating side. The advancing side of the weld experiences a higher relative velocity in relation to the tool, while there treating side experiences a lower relative velocity. This nomenclature is dependent upon the direction of tool rotation and travel.

II. IMPORTANT WELDING PARAMETERS

Tool Design: The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. It is desirable that the tool material be sufficiently strong, tough, and hard wearing at the welding temperature. Further it should have a good oxidation resistance and a low thermal conductivity to minimise heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminium alloys within thickness ranges of 0.5 – 50 mm but more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites or higher melting point materials such as steel or titanium.

The majority of tools have a concave shoulder profile which acts as an escape volume for the material displaced by the pin, prevents material from extruding out of the sides of the shoulder and maintains downwards pressure and hence good forging of the material behind the tool.

Widespread commercial applications of friction stir welding process for steels and other hard alloys such as titanium alloy will require the development of cost-effective and durable tools. Material selection, design and cost are important considerations in the search for commercially useful tools for the welding of hard materials. Work is continuing to better understand the effects of tool material's composition, structure, properties and geometry on their performance, durability.

Tool rotation and traverse speeds: There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses the interface. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the welding speeds and the heat input during welding is complex but, in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld. In order to produce a successful weld it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cold then voids or other flaws may be present in the stir zone and in extreme cases the tool may break.

Excessively high heat input, on the other hand may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of low-melting-point phases (similar to liquation cracking in fusion welds). These competing demands lead onto the concept of a "processing window": the range of processing parameters viz. tool rotation and traverse speed that will produce a good quality weld. Within this window the resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively deteriorated.

Tool tilt and depth: The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality. Plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2–4 degrees, such that the rear of the tool is lower than the front, has been found to assist this forging process. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Given the high loads required, the welding machine may deflect and so reduce the plunge depth compared to the nominal setting, which may result in flaws in the weld.

III. LITERATURE SURVEY

Friction stir welds have been produced in a wide variety of metals, all requiring different energy inputs and different types of tooling. The energy input per unit length in FSW is primarily a function of the variables of tool rotational speed and traverse speed, requiring that these welding parameters be modulated for each alloy to input sufficient energy to form a solid joint (Mishra & Ma, 2005). Welding dense, strong materials requires very high energy input and consequently higher power machinery. Because of the low density and strength of aluminium, FSW in aluminium requires a lower input energy than FSW in other common aerospace and transportation materials such as titanium and steel. The low strength of aluminium permits steel tooling to be used, further lowering the cost of implementing FSW manufacturing solutions for aluminium.

Research in the mechanics of the FSW process has determined the method by which FSW causes fusion. As the tool rotates, it builds energy in the material immediately surrounding it and in the direction of the tool traverse. With roughly each full rotation, the tool builds enough energy to extrude a semi-circular shell of the base material from the front of the tool to the rear side of the tool. The entire weld is produced in this manner, meaning that the weld zone is essentially

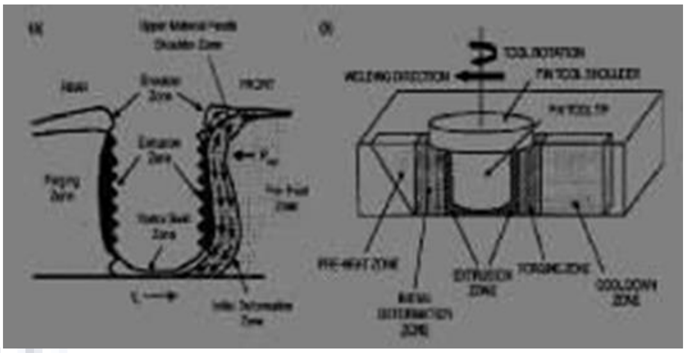

Fig 2:a) Shows zones of different mechanical processes, and b) depicts the mechanical interactions determining these processes.

The shell extrusion process causes local strain significant enough to refine both primary and secondary phases in friction stir welds. Accordingly, this process can be used as a method to refine microstructures with problematic secondary phases and salvage material properties(Elangovan & Balasubramanian, 2008).

Using the process in this manner is called Friction Stir Processing (FSP); it has been suggested that FSP could be used on castings to provide an increase in material properties across large areas of the part through dissolution of secondary phases and grain refinement. The size and dispersion of grains and secondary phases is determined extensively by the welding parameters, thus significant modulation of result an microstructures is possible. The benefits of primary and secondary phase refinement also apply to welds produced using the FSW process.

Kwon et al Mishra & Ma.(2002 and 2005) Grains have a higher degree of plastic deformation closer to the weld and nearer to the tool shoulder, tapering to grains that are less deformed further from the weld center line.

Mishra and Ma. (2002,2005) The HAZ is defined by heat input to the workpiece, which is a function of the welding parameters. The welding parameters may vary significantly depending on the nature and intent of the process, resulting in a significant variation in corresponding HAZ width and properties.

Kwon, Saito, & Shigematsu(2002) Welding dense, strong materials requires very high energy input and consequently higher power machinery. Because of the low density and strength of aluminum, FSW in aluminum requires a lower input energy than FSW in other common aerospace and transportation materials such as titanium and steel. The low strength of aluminum permits steel tooling to be used, further lowering the cost of implementing FSW manufacturing solutions for aluminum.

IV METHODOLOGY

Fixtures and Tooling:

The fixtures were made from an Al6061- T6511 extrusion with a separate base piece and top piece with inset pockets to firmly hold the welding samples. These fixtures minimized travel on all axes as well as quickly conducting heat away from the workpiece to maintain consistent time-temperature distributions in the weld. The base plate and upper plate can be seen in Fig 3

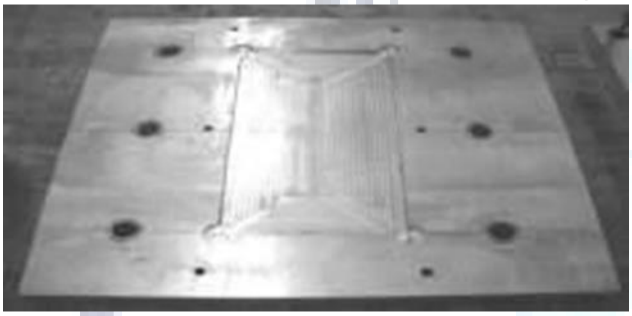

Figure 3: Shows fixture made from Al6061

Tool Manufacturing Process Adopted:

A 6mm welding tool designed for use in Al6061-T6 was manufactured. When fixture was tightened, the total weld length possible was 10mm with a weld penetration of just over 6mm (minimal tool shoulder penetration). All welds were performed on friction stir welding machine. The tool chosen for the FSW operations of this project was a cylindrical tool made from high carbon hardened steel set into a steel tool holder. The tool bit used in this experiment made up stainless steel- H13, designed as shown in figure 4.

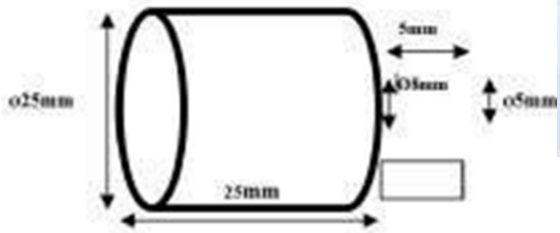

Figure 4: Tool bit dimension used in friction stir welding

In the manufacturing of the tool we have taken a stainless steel work piece of diameter 30mm and length of 35mm having hardness H-13. By using facing operation the length has been reduced to 30mm by operating at low rpm in order get smooth surface and as it is having high hardness, the machine has to be run at low rpms. Then, went for reducing the diameter and reduced it by 5mm. For 5 mm distance from the starting point from the right side gone for step turning. Each time reduced 1mm for 20 times.

As the machining was done some of the properties might have varied. Hence, In order to regain some of the properties such as hardness heat treatment has done. Firstly the tool bit was exposed to 950 degree Celsius for four hours and then it was quenched in ice water in order to increase its hardness. But due to sudden quenching hardness at several points it may be different. So in order to get uniform properties the tool bit was exposed tempering for 200 degree Celsius and then it was cooled in normal air. Hence may get to uniform properties.

Microstructure and Hardness of As-FSW Rolled Al6061-T6:

Al6061-T6 aluminium was used as the base material in this study. The material is readily available and was acquired from a local provider. Mass spectrometry was performed on theAlloy purchased in order to pinpoint composition. Table-1 provides the composition detail.Table -2 describes the properties of the as-rolled Al6061-T6 alloy.

Table -1 shows composition of different elements in Al6061

Element detected	Mg	Fi	Cu	Si	Mn	Cr	Ti	Al
% composition	0.9	0.38	0.26	0.64	0.03	0.21	0.02	Balance

In rolled form, this alloy has a grain structure that varies significantly between the rolling direction and transverse direction. The grain size was found to be approximately 50μm in the rolling direction. An image of the microstructure of the base alloy can be found in Figure 5

Figure 5: shows the microstructure of the rolled Al 6061

Table -2 Shows Tensile properties of rolled Al6061 parent metal Figure 6: shows the samples for hardness test

Property of Al6061	Corresponding value
Vickers Hardness	107
Ultimate Tensile Strength (UTS)	46ksi
Yield Strength	42.3psi
Elongation at break	17.00%
Modulus of elasticity (E)	9400ksi

WELD CREATION:

The welds were created with 5 cm length and 2 cm width of Al606 of friction stir welded bead for analysing the hardness values from the baseline of the specimen to the end. Three specimens of equal dimensions were used for finding the hardness. Below figures will give idea about the specimens.

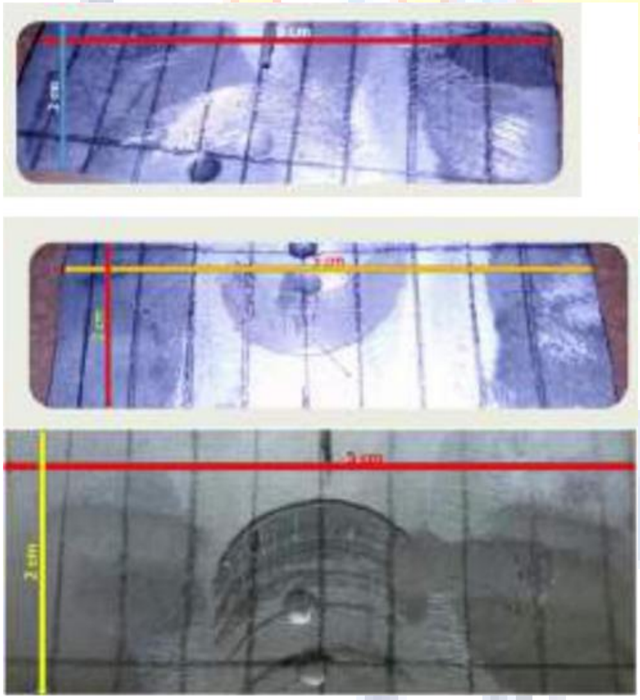

Figure 6: shows the samples for hardness test

900 rpm and 45mm/min
1200 rpm and 45 mm/min
1500 rpm and 45 mm/min.

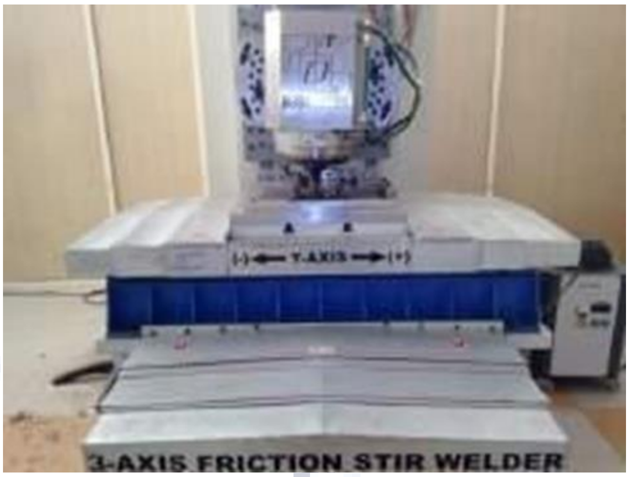

Figure 7: friction stir welding setup

Figure 8: shows the specimens used for hardness test

IV. RESULT AND DISCUSSION

Baseline Welding Parameters:

Table -1: Diameter of indentation and BHN for 900 rpm and 45mm/min

Diameter of indentation (mm)	BHN
4.2	34.447
3.7	44.88
3.5	49.776
3.6	47.505
3.7	43.859

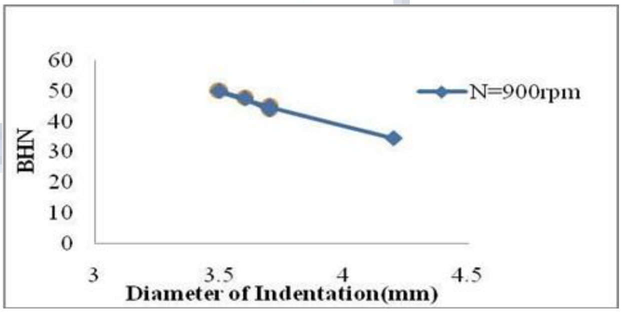

Figure 9:shows how hardness varies from baseline to edges for N=900rpm for V=45mm/min

The large difference in grain sizes between unaffected material and the DXZ is apparent even at extremely low magnification, as is the appearance of onion rings. As found in other studies, the advancing side of the weld is defined by sharply upturned grains in a thin TMAZ; the retreating side of the weld demonstrates a DXZ that more smoothly blends into the HAZ through an extended TMAZ.

Table-2: Diameter of indentation and BHN for 1200 rpm and 45mm/min

Diameter of indentation (mm)	BHN
3.7	45.289
3.4	53.458
3.2	63.225
3.3	56.88
3.5	50.352

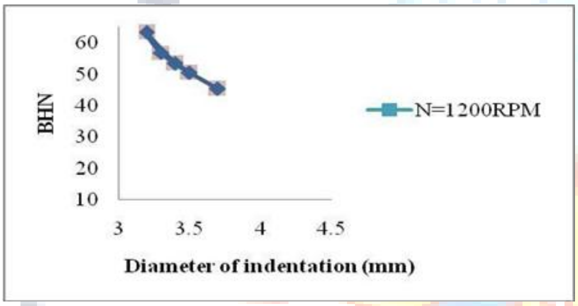

Figure 10: shows the variation of the hardness profile from baseline to edges for N=1200rpm for V=45mm/min

The outer edges of this distribution would be expected to continue to increase in hardness until reaching the unaffected base material value; at no point is the hardness greater than that of the unaffected base material. It is likely that the relatively high hardness of the DXZ is due to the small grain size, while the low hardness of the TMAZ is due to dissolution of strengthening precipitates and the low hardness of the HAZ is due to coarsening and clustering of precipitates.

Table-3: Diameter of indentation and BHN for 1500 rpm and 45mm/min

Diameter of indentation (mm)	BHN
3.9	40.225
3.3	56.88
3.1	60.469
3.5	50.352
3.6	47.505

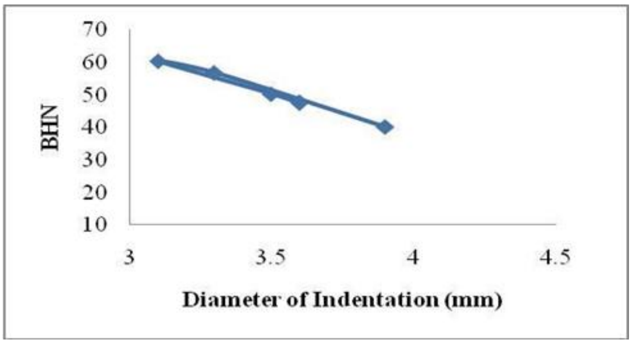

Figure 11: shows the variation of the hardness profile from baseline to edges for N=1500 for V=45mm/min

From the above three figures it is clear that the hardness value at the baseline it is more compared to the other regions. At the baseline (DXZ zone) the grain size is very less compared to other regions (TMAZ and RXZ).As we go from baseline to edges the hardness comes to match with the parent

IV CONCLUSIONS

The analysis performed on microstructure and hardness in the Al6061 demonstrates relationship between material properties and the response of welds to static loading. Comparison of microstructure and hardness profiles of the welded Al6061 to the parent metal it has been observed that the hardness is varying from the base line to the edges. The results demonstrate that the hardness profiles of the sample are the result of the welding parameters selected and there for tensile properties are also the same. From the hardness profiles that we have got it is inferred that as we move from base line to edges the hardness fluctuates and reaches to parent metal value. Higher hardness value may be observed at the Dynamically Recrystalized Zone than Thermo Mechanically Affected Zone and Heat Affected Zone. From the previous studies it has been seen that the grain structure is fine at the DXZ zone compared to the TMAZ and HAZ.

V .FUTURE WORK

Future work could be built upon this study by conducting several static and dynamic tests.
These may include:

Perform several tensile tests by taking different set of welding parameters.

Can take up specific region from those regions that are observed in the Friction Stir Welded sample and perform several tests.

Can go for dynamic and Static for the different set of welding parameters by keeping traverse speed constant and/or keeping rpm constant.

Can take up the task related to designing of the FSW tool which has conical pin probe which will easily escape from the weld when we stop the welding.

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