A Weldment characteristics on Friction stir welding process for shipbuilding materials

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Abstract. The Friction stir welding Process(FSW) is a solid state welding process that is used on metals where the original characteristics of metal remain as unchanged as possible. The technique has a energy efficient, environment friendly, decrease the fuel consumption and improve the metal performance. These study address the comparative performance of process parameters of Aluminium alloys 5052, 6061 using Friction stir welding. The tool pin probe plays a major role in processing and solidification of joints. The combination of low welding speed and high rotational speed respond the excessive flash generation and formation of grains. A Microstructure of the welded joint were observed by using scanning electron microscopy (SEM). The results exhibits a fine Coarsening and Dissolving of precipitates in weld nugget zone(WNZ). Tensile property shows that the heat treatable alloys undergoes increase in strength value. The Micro-Hardness value decreases gradually to the base metal of welded joints. The corrosion study suggested the no type of corrosion occurs in heat and non heat treatable alloys for 96 Hours.

1. Introduction
The Friction stir welding(FSW) was invented by the welding institute(TWI) in UK in 1991 as a green solid state joining techniques[1]. They have a direct conversion of mechanical energy in to thermal energy. The process of FSW uses a cylindrical tool probe which is rotated at constant speed and then placed in to a joint between the two pieces of metal which are to be joined together. Once the process is started friction heat is created between the welding shoulder and metal being joined together. The heat is created by the mechanical mixing process and adiabatic heat in metal cause the metals to soften to a point just higher than the melting point. This allows the tool to move along the weld line of metal. The FSW process produce a fine specimen in the range of 20-200rpm. Among the Merits of FSW it is environment friendly welding technology, low energy requirement, no generation of toxic fumes and does not require consumables.[2]. The FSW has rapidly developed form experimentation to applied technology which has now been deployed in to Aerospace, Automotive, Shipbuilding. Defense with huge research and development[3]. The advantages of Friction stir welding includes the absence of toxic flames, absence of weld spatter, no smoke, no dust and gas. It does not bring the welding defects of welding shrinkage, voids, worm holes etc. Initially FSW method is created for joining a Aluminum alloys but since it has been applied to join many materials. They joining at temperature below the melting point. It eliminates many fusion welding problems such as porosity, segregation of alloying elements and solidification defects[4]. Now FSW Process is used to weld Magnesium alloy, copper, alloy steel, tool steel and composite. It has a excellent weldability of similar and dissimilar aluminum alloys. The application of aluminum alloy is increasing in all industries due to the combination of...
property of low weight, good mechanical resistance and corrosion resistance[5]. Typically ship building industries applies wrought aluminum alloy series of 5xxx and 6xxx [6,7]. The important factors involve in material flow a tool geometry of Tool pin, shoulder and welding parameters of Material type, workpiece temperature etc.

2. Tool Nomenclature

The tool geometry is a most influential aspects of process development. It plays a crucial role in material flow and it turns governs the transverse rate at which FSW can be conducted. The tool has a primary functions a localized heating and material flow. The tool serves the three functions of that is heating of workpiece, movement of material to produce the joint and containment of hot metal beneath the tool shoulder. The heat is created within the workpiece both by friction between the rotating tool pin, shoulder and severe plastic deformation of workpiece[8]. It is explained the tool probe is shorter than the thickness of workpiece. The stirring of tool is minimize the risk of having excessive local amounts of inclusion, resulting in homogenous and void free weld[9]. It is to be found that joint weld at lower rotation speed trend to be fracture in stir zone and at higher speed the hardness is increase in stir zone and defect free in Thermo-mechanically affected zone(TMAZ) and Heat affected zone(HAZ)[10].

The initial stage of tool plunging the workpiece leads to heat result from the friction between tool and workpiece. The rotation of tool results in stirring and mixing of material around the rotating pin and translation of tool moves the stirred material from to the back of pin. The shape of the tool pin influences the flow of plasticized the material and affects the weld properties. The friction between the tool and workpiece exhibits a biggest component of heating[11]. The Tool shoulder provides the confinement for the volume of material. The second function is to stir and moving. They are designed to produce heat in surface and subsurface region. In these experiment FSW of Aluminum alloys used a Threaded cylindrical pin. The D2 tool (High carbon and high chromium) is used. D2 tool steel has a good wear resistance, corrosion resistance and better hardenability. The D2 tool is hardened and Tempered at suitable condition. The chemical composition of D2 tool steel is illustrated in the Table 1 and Table 2. In frustum type pin shows a less removal of material in the processing[12]. The tapered pin profile with screw thread produce weld with minimum defects in Al alloys[13]. For the conventional butt welding a threaded tool pin results in excessive thinning of top sheets leading to significantly reduce the bend properties[14]. It is reported that if a Rotating pin travelled along the butt line between the two base metal and joined[15]. A high heat input could increase the amount of intermetallic compounds and then decreased the mechanical properties., Even so the heat input should not be too low. Reason of an extremely low heat input could result in imperfect action [16]. The Temperature distribution between the advancing side(AS) and Retreating side (RS) is asymmetric and it is skewed to advancing side and toward the leading edge of tool[17]. The material flow behavior of Al-6061 shows a TMAZ exhibits a uniformly distributed particle. Second of HAZ exhibits a plastic deformation, like vortex structure. Third of WNZ shows a fine equiaxed grains[18]. It is found that FSW of magnesium and aluminum 6061 alloy represents the WNZ shows a defect free weld but the micro-hardness distribution in weld was uneven[19]. The backwash and wash of threads is caused due to the large vertical movements of material within the stir zone[20]. In FSW very high pressure leads to over heating and thinning of joint, whereas the lower creates the insufficient heat and void. The chemical composition of D2 Tool steel can be found in Table 1.

| Table 1. Chemical composition of D2 Tool steel |
|----------------------------------------------|
|    Al    |    Mg    |    Si    |    Mn    |    Ti    |    Cr    |
| Al-5052  |  95%    |  2%      |  0.6%   |  0.8%   |  0.5%   |  0.7%   |
| Al-6061  |  95.8%  |  1.8%    |  0.8%   |  0.5%   |  0.67   |  0.79   |
A commercially plate of 100X50X5mm Square shape d specimen were used in FSW Process. The metals that are clamped on to a backing bar so that their joint faces cannot be forced apart by the process. The FSW tool comprises the 18mm shoulder diameter and pin diameter is 6mm. Normally the shoulder diameter is three times the tool diameter. The process parameters of welding speed and rotational speed were taken in friction stir processing is 800 to 1200rpm and 10 to 20mm respectively. The axial force of 10KN and butt type is applied in CNC Configuration vertical milling machine. The Mechanical properties of D2 tool steel was found in Table 2.

**Table 2. Mechanical properties of D2 Tool steel**

| Characteristics                  | Optimum range |
|----------------------------------|---------------|
| Ultimate strength(mpa)           | 780           |
| Yield strength(mpa)              | 210           |
| Elongation                       | 0.27-0.30     |
| Thermal expansion                | 20-100        |

The insertion depth of pin in the workpiece is associated with pin height. The tool touches the workpiece which results in generation of weld in inner channel. In shoulder majority of height is generated by friction of heat. For the materials of low melting point Al, Mg shows a re-crystallized grains around the weld zones. The important factor of tool design is adequate amount of material flow and quantity of welding. Table 3 Describes the chemical composition of Al-alloys.

**Table 3. Chemical composition of Aluminum alloys**

|        | Al  | Mg  | Si  | Mn  | Ti  | Cr  |
|--------|-----|-----|-----|-----|-----|-----|
| Al-5052| 95% | 2%  | 0.6%| 0.8%| 0.5%| 0.7%|
| Al-6061| 95.8%| 1.8%| 0.8%| 0.5%| 0.67| 0.79|

3. **Experimental Procedure**

The Friction stir welding (FSW) plays a major role in joining of al-alloys. During a initial stage of plunging the large forces acts on the workpiece. A rotating pin is plunged through the upper plate and in to lower plate and transverse along the desired direction and joining the plates. Tool rotational speed and welding speed of bed were set to prior each run of the weld.

**Table 4. Process parameters of FSW**

| Parameter     | Values         |
|---------------|----------------|
| Tool rotation | 800 to 1000 rpm|
| Welding speed | 10 to 20min    |
| Axial force   | 10 KN          |
| Tilt angle    | 5°C            |
The Friction stir welding is shown in Figure 1. The welding traverse speed, rotational speed, tilt angle and tool design are the main variables to control the process. In these experiments, the input variables of tool rotational speed and welding speed and other variables of tilt angle and axial force were set to be constant. The Experimental parameters of FSW can be found in Table 4. The tool influences the heat generation, plastic flow, the power required to perform the FSW and uniformity of weld joints. The insertion of plunging tool in butt joints ensures the full contact of tool shoulder plate surface. The Friction stir welding machine and tool is shown in Figure 2.

![Figure 1. Friction stir welding](image1.png)

Figure 1. Friction stir welding

![Figure 2. Friction stir welding machine and Tool](image2.png)

Figure 2. Friction stir welding machine and Tool

4. Mechanical Properties

4.1 Microstructure Characteristics

The Microstructure investigation provides a more detailed regard weld microstructure. Each sample was taken from the cross section of weld area. Based on the study of Grains, precipitates of FSW exist in three zones as Thermo-mechanically affected zone(TMAZ), Heat affected zone(HAZ), Weld nugget zone(WNZ). The WNZ experiences intense deformation and high temperature exposure. The Precipitates and coarsening effect exhibit around the stir zone. The pin slightly larger than the pin diameter except at the bottom of weld. The friction heat depends upon the surface velocity and friction coupling. The Parent material of Al-alloys is shown in the Figure 3. The TMAZ of the welded joints consists of smaller size grains due to deformation of region adjacent to WNZ. The HAZ of weld joint shows no significant changes in the microstructure. The three zone experiences a different microstructure changes includes as grains, dislocation, density, precipitates size and distribution. The
WNZ region undergoes a deeply deformed in metal areas. Grains in the region shows a smaller size than the base metal. This is due to the continuous dynamic recrystallization. TMAZ occurs on either side of stirring area. The strain and temperature levels are lower and the effect of welding on the material structure is eliminated in these region. The Figure 4 Displays the WNZ of weld joints. The heat affected zone (HAZ) is subjected to thermal cycle but it is not deform during the welding of Al-6061.

![Figure 3. Parent material of Al-5052 and Al-6062](image)

![Figure 4. WNZ of Al-6061](image)

![Figure 5. TMAZ of Al-5052.](image)

The cross section area of the welded specimen shows an increase in grain size in middle region and grain size is reduce in lower part of the region. It was noted that grain size is reduce by decrease the tool rotation speed. The interface between the re-crystallized weld nugget zone and parent material is relatively diffuse in Retreating side. The top of the weld grains is coarser than the base metal. At the bottom of the weld despite the average grain being similar to the base metal. The TMAZ of Al 5052 is shown in Figure 5. The grain size distribution is different in microstructure transformation in WNZ of Al-5052 alloy. It experiences grains caused by mechanical action of tool probe that generates the continuous dynamic re-crystallization.

4.2 Tensile Characteristics
The Tensile characteristics of FSW experiences the Yield strength, Percentage of elongation, Tensile strength, The Transverse rotational speed and welding speed were dominated by tool shoulder. The tensile specimen were taken from the Weld stirring area of joints in longitudinal and Transverse direction. The tensile work were carried out by ASTM standard B557M. The Tensile parameters of Al-5052 is shown in Table 5.
Table 5. Tensile parameters value of Aluminium alloy 5052

| Rotational speed (Rpm) | Welding speed (mm/ min) | Tensile strength (N/ mm²) | Yield strength (N/mm²) |
|------------------------|-------------------------|---------------------------|------------------------|
| Sample 800             | 10                      | 133.4                     | 113.3                  |
| 900                    | 10                      | 130.5                     | 110.7                  |
| 1000                   | 20                      | 141.4                     | 108.6                  |

Table 6. Tensile parameters value of Aluminum alloy 6061

| Rotational speed (Rpm) | Welding speed (mm/ min) | Tensile strength (N/ mm²) | Yield strength (N/mm²) |
|------------------------|-------------------------|---------------------------|------------------------|
| Sample 800             | 10                      | 153.6                     | 126.8                  |
| 900                    | 10                      | 150.8                     | 114.7                  |
| 1000                   | 20                      | 149.7                     | 107.8                  |

The Tensile results shows increase in strength and ductility for High rotation speed due to intense plastic deformation and heat generation. The Tensile parameters of Al -6061 can be found in Table 6. The Tensile region of WNZ exhibits a strongest region and other regions experiences the deformation and dislocation in joints, Analysing the result in all joints we concluded a good mechanical performance reaching tensile shear strength values close to the base metal. There is no significant difference between the advancing side and retreating side of joints.

4.3 Micro-hardness characteristics

The Vickers Micro-Hardness tester were used for the hardness measurement. Samples were taken from the cross section of welded joints. The indentation load was kept at 100grams. Measurement was taken from the 15mm from the centre portion of weld region from both sides in Transverse direction. Hardness in WNZ exhibits the little higher hardness than TMAZ, HAZ. The sample of low welding speed and high rotational speed of FSW leads to excessive flash generation and formation of grains. Advancing side of FSW shows lower hardness value than the retreating side. A Micro-hardness results of Al-5052 can be found in Table 7. Increasing of rotational speed leads to smaller hardness value in weld stir regions and grains in areas become larger. The hardness in middle region of welded joint decreases continuously in the hardness value from base metal to stir zone. The little variation in hardness value along the bottom region. The Micro-hardness property of Al-6061 can be found in Table 8.

Table 7. Micro-Hardness Properties of Al-5052

| Rotational speed (rpm) | Weld speed (mm) | WNZ  | HAZ  | TMAZ | parent material (BHN) |
|------------------------|-----------------|------|------|------|------------------------|
| 800                    | 10              | 95.6 | 91.7 | 89.4 | 98.6                   |
| 900                    | 10              | 93.4 | 89.4 | 86.5 | 93.4                   |
| 1000                   | 20              | 96.4 | 91.2 | 90.3 | 96.4                   |
Table 8. Micro-Hardness Properties of Al-6061

| Rotational speed (rpm) | Weld speed (mm) | WNZ | HAZ | TMAZ | parent material (BHN) |
|------------------------|-----------------|-----|-----|------|------------------------|
| 800                    | 10              | 73.2| 78.4| 74.3 | 76.4                   |
| 900                    | 10              | 73.4| 68.7| 65.3 | 71.6                   |
| 1000                   | 20              | 70.3| 67.8| 64.3 | 68.7                   |

4.4 Corrosion Characteristics
The corrosion work of Al 5052 and Al 6061 has been widely investigated by using corrosion test (Acid Salt spray). It is very important to understand the corrosion behaviour of Al- alloys. The tested specimen is concentrated 0.5ml NaCl at 40˚C for 96 hours and measuring mass. The corrosion test was operated by using a standard procedure of ASTM B117. The results of test exhibits a case of phase transformation induced in alloy structure often result in deep modification of material properties. It is pointed out the high rotational speed can improve the corrosion resistance of welded joints in Al-alloys[21].

Table 9. Corrosion Requirements

| Requirements                      | Specification       |
|-----------------------------------|---------------------|
| Distilled water by weight         | 95 parts            |
| Sodium chloride (%)               | 5 parts             |
| Specific gravity of liquid        | 1.26 to 1.014       |
| Ph (35± 1˚c)                       | 6.5 to 7.2          |
| Temperature                        | 35± 3˚c             |

The corrosion characteristics results shows the no amount of corrosion occurs in Al alloys. Table 9 Describes the corrosion Requirements. No amount of rust is take place in both side of welded joints. Both the Aluminium alloys represents a good corrosion resistance in EXOC solution.

5. Conclusion
The comparative study of Heat treatable and Non-heat treatable alloy of Friction stir processing exhibits a good joints in the solidification. The threaded tool produce a better mechanical properties in all the rotational speed of tool. The Tool shoulder plays a dominated role in all joints. When we increased the speed of tool, It leads to increase the hardness in some areas. It experiences a generation of high temperature and intense plastic deformation. The WNZ shows a small deformed structure in zone areas of A-5052. The Microstructure characteristics address the little deformed structure in TMAZ. In WNZ little grains and precipitates occurs. The heat affected zone of FSW prescribe that no deformation occurs in all joints area of Al-6061. In Tensile Testing of the welded joints experiences the strength was decreased compared to base metal in both aluminium alloys. It outlines the increase the welding speed leads to decrease the Tensile value. The good joining of welded specimen occurs in 800rpm and 900 rpm in both the alloys. The Micro-Hardness result of the advancing side of Al-alloys shows a lower hardness value compare to Retreating side. There is little variation in Hardness in the weld stir zones. The corrosion Behaviour of Al alloys in FSW represents no amount of rust, crack and
corrosion occurs in all welded joints. From the experiment we concluded the Al-6061 exhibited a good joining efficiency than the Al-5052.

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