1. Introduction

Friction Stir Welding (FSW) is a solid state welding process where joining takes place below melting temperature of material this characteristics greatly reduces distortion shrinkage, porosity, eliminates solidification defects. FSW has been proven to be an effective process for welding Aluminium alloys, Titanium, Copper, Zinc, Steel, Magnesium, Cast iron\(^1\)-\(^7\). Today FSW is used in research and production in many sectors, including aerospace, automotive, railway, ships building, electronic housings, coolers, heat exchangers, and nuclear waste containers. Main advantages of friction welding are high material saving, low production time and possibility of welding of dissimilar metals or alloys. For example engine pistons, mainly for truck applications can be friction welded\(^1\),\(^4\),\(^5\). In this process a rotating tool with a pin extending from a larger shoulder is translated along the weld joint. This tool during its path produces frictional heating with temperature below the melting point and the plastic deformation due to the stirring of the material around the pin, produces the weld. The process can be regarded as solid-phase keyhole welding technique since a hole to accommodate the probe is generated, after getting in appropriated position the rotating tool produces heat due to friction between the tool and work pieces then moved along the weld. Hence the joining of the plates is performed.

In this work, friction stir welding is carried out between Al 7020 plates with Mg as the interlayer. The
Defect Analysis on Al 7020 FSW Joints with Mg Interlayering

Joints are made between plates with magnesium as interlayer by varying the travel speed of the tool 10, 15, 20, 25, 30mm/min respectively by keeping the tool rotation and feed rate as constant parameters. Tests such as tensile test, Rockwell hardness test where carried out in the FSW joints to find out the mechanical properties of the joints.

A Universal Testing Machine (UTM), materials testing machine is used to test the tensile strength of the joints. The UTM is done by preparing the specimen according to the dimensions and subjected to tensile force which will continued till it breaks and thus we could know the maximum possible strength it posses.

2. Result and Discussion

2.1 Rockwell Hardness Test Result
The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, where A is the scale letter.

From the graph 2a (Figure 1.) we came to know that the specimen with travel speed of 10mm/m shows greater hardness than the other specimen, following 25mm/m and 20mm/m shows second and third most hardness value respectively. The specimen with 15mm/m shows least hardness value during test.

The Rockwell hardness test is performed on each specimen in three zones namely stirrs zone (middle zone of the weld), retreating side and advancing side of weld. The hardness is test done in stir zone or nugget zone which is of 49HRB. The hardness of the retreating side is 48HRB and the on advancing side is 48.5HRB.

The hardness test result shows that the test specimen of 10mm/min traverse speed has maximum hardness as compared to the other specimens. Here is the conflict i.e., for the same specimen tensile strength also high so we could go for scanning electron microscopy analysis.

2.2 Tensile Test Result
The tensile sample was prepared as per (ASTM E8M-04) standards. There after test is carried on the weld specimen with Mg interlayer of 5µ. The results of the tensile test are shown in the Table 2 below. The specimen with 10 mm/min of traverse speed has high tensile strength with ultimate tensile stress of 237N/mm².

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Travel Speed of Tool (mm/min)</th>
<th>Ultimate Tensile Stress (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>237.1</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>39.9</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>74.7</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>98.8</td>
</tr>
</tbody>
</table>

Figure 1. Travel speed vs. hardness.

Figure 2. Travel speed vs. ultimate tensile stress.

Table 1. Test results for various travel speeds

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Travel Speed of Tool (mm/min)</th>
<th>Observed Rock well hardness values (HRB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>48.7</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>40.7</td>
</tr>
<tr>
<td>3</td>
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<td>46.7</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>48.3</td>
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</table>
Thereafter test is carried on the weld specimen with Mg interlayer of 5µ. The results of the tensile test are shown in the Table 2. The specimen with 10 mm/min of traverse speed has high tensile strength with ultimate tensile stress of 237N/mm². From the plots of travel speed vs. ultimate tensile stress (Figure 2.) it is very clear that when the travel speed of tool is decreased to 10mm/min the strength gets increased. While it is 15, 20, 25, 30 mm/min the strength is lesser than 10mm/min travel speed sample. For further analysis and studies about this character we can go in depth with Scanning Electron Microscope (SEM) and Energy Dispersive X-ray spectroscopy (EDX).

3. Defect Analysis

The type of defect found in this specimen is intergranular stress corrosion fracture; it is defined as grain boundary separation. It can occur by separation of microvoid coalescence on the interface of grains. It is due to severe reduction in grain boundary energy by Gibson adsorption mechanism.

With an interlayer (Mg) thickness 5µ we could see improper or uneven dispersion of raw material in forward and retreating zones in 15mm/min travel speed. This may lead to the defects/fracture like cleavage and Void and thermal stress accumulation also possible on the edges of these defects. This causes a reduction in tensile strength.

When doing welding with 10 mm/min travel speed (Figure 3.) all the above said defects were removed and only identified fracture morphology is deformed transition zone. It caused by the compressive fatigue cycles. This can be avoiding by slightly improving the weld speed, hence it helps to avoid over drive of shoulder in a same spot again.

Examination by Scanning Electrode Microscopy (SEM) of the origin of fracture at the weld joint reveals dimples formations characteristics of ductile tensile failure. High magnification image of the fracture surface opposite the weld failure clearly displays two distinct fracture surfaces. Figure 4 depicts the weld nugget, which displays transgranular cleavage enveloped by regions of ductile, tensile, dimples.

4. Conclusion

The result of this work predicts weld specimen with Mg interlayer of 5micron with 10mm/min tool travel speed shows higher tensile and hardness strength than other specimens with travel speed of 15, 20, 25 mm/min.
In the defect analysis on Al 7020 FSW joints we found intergranular stress corrosion fracture and dimples plus intergranular cracks, as per ASTM standards. The reason of this defect or crack may be occurred due to uneven heat dispersion, presence of impurity, vibrations, or oxide formations, which are common problems arises during FSW. But we can remove these problems by preheating specimen surface. Cleaning specimen by proper techniques: Avoiding unwanted vibrations and movements of machines. To go further the research can be extended with pre and post heat treatments to improve the grain structure and to avoid deformed transition zone. If the transition layer is vanished the strength will becomes similar to parent metal.

5. References