Analysis of FSW Welds Made of Aluminum Alloy 6110

Jarot Wijayanto¹ Sudarsono² and Rizqi Fitri³
¹²³ Departement of Mechanical Engineering,
Institute of Science and Technology of AKPRIND Yogyakarta,
Jl. Kalisahak No.28 Kompleks Balapan, Yogyakarta 55222, Indonesia.
Email: jroat@akprind.ac.id / j_wijayan_to@yahoo.co.id

Abstract: The aim of the studies was to analysis the micro structure and mechanical properties changes in friction stir welds (FSW) in the aluminum alloy 6110 in function of varying process parameters. The test is micro structure testing to analysis the effect of the welding process to welding zone. Micro structure in the area of welding and parent material is essentially unchanged, but on the thermo mechanically affected zone (TMAZ) grain is distorted so that looks like onion rings. The test is the hardness testing to analysis the effect of welding process on the TMAZ and weld zone hardness. Occurred a significant decline in the value of violence in the region of weld metal, HAZ and base metal of the parent material, but for variable 320 mm / min occurred narrowing the weld area. The last test is tensile strength testing to analysis the mechanical properties of welding zone. Among the variables that have been investigated, stress and strain values is best on variable feed rate 320 mm/min (8.86MPa with 2:17% strain).

Key words: welding, FSW, Aluminum Alloy, TMAZ

1. INTRODUCTION

FSW was invented and patented in 1991 by TWI and has since been developed to a stage where it is being widely applied in production[4]. In manufacture of transport system, aluminum alloy applications are advancing particularly strongly to achieve lighter-weight automotive structure, FSW being effective for this purpose [5]. FSW process operates at relatively low temperatures. The heat generated from friction between the work piece and the tool rotates, under a large axial pressure on the welding area. This process is typically used in applications that require without any change in the characteristics of the base metal. The material around the tool becomes softened and highly plasticized from the frictional heat generated during the process and is carried around the tool so that there is complete mixing of material from the two plates. In full penetration welding the tool probe extends almost through the thickness of the plates to be welded, but in partial penetration the probe can be much shorter. Because there is no melting or resolidification of material, there is usually lower distortion introduced by this welding process compared with other welding processes [4].

In FSW, a cylindrical-shouldered tool, with a profiled threaded/unthreaded probe or pin is rotated at a constant speed and fed at a constant traverse rate into the joint line between two pieces of sheet or plate material, which are butted together as shown in Figure 1. The parts have to be clamped rigidly onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. The length of the pin is slightly less than the weld depth required and the tool shoulder should be in intimate contact with the work piece surface. The pin is then moved against the work piece, or vice-versa. Frictional heat is generated between the wear resistant welding tool shoulder and pin, and the material of the work-pieces. This heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without reaching the melting point (hence cited a solid-state process). As the pin is moved in the direction of welding the leading face of the pin, assisted by a special pin profile, forces plasticized material to the back of the pin whilst applying a substantial forging force to consolidate the weld metal. The welding of the material is facilitated by severe plastic deformation in the solid state involving dynamic recrystallization of the base material [3].

Figure 1. A Schematic of FSW (butt-welding) [3].
2. MATERIALS AND METHODS

2.1. Material
The materials used in this study are aluminum alloys 6110 in the form sheets of thickness of 3.8 mm. The composition of the alloys was following (wt%): 0.12% Si, 0.87 Fe, 0.22 Cu, 0.25 Mn, 0.75 Mg, 0.01 Cr, 0.02 Ni, 0.33 Zn, 0.28 Ti, 0.01 Pb, 0.01 Ca, 0.02 Zr. Welding Parameters: The butt joints were made parallel to the rolling direction at rates of rotation 3600 rpm and linear velocity of the tool 40, 64, 93, 200 and 320 mm/min. A high-speed steel tool was used for welding 6110 Al alloy having the shoulder diameter of 12.5 mm. The tool had a pin height of 3 mm and a 3 mm pin diameter.

2.2. Methods
Methods: The friction of two objects which will continually produce heat, it becomes a basic principle of the creation of a friction welding process. In the process of FSW, a tool that rotates the material to be emphasized at united. Friction cylindrical tool (cylindrical-shoulder) equipped with a pin / probe with the material resulted in local heating which can soften the part. Tool moves at fixed speed (parameter 1) and move across (parameter 2) on the welding line (joint line) of the material to be incorporated. Two parameters were driven together to keep the temperature at the welding point. The FSW plates were taken for microstructure, hardness and tensile strength evaluation. Only those sample plates that qualified in the aforementioned tests were taken for detailed microstructure characterization. For the optical microscopy the samples were cut in a direction perpendicular to the welding direction. These samples were then ground, after which they were polished to obtain a mirror finish. The samples were then etched using a solution of 10 ml HF + 15 ml HCL + 25 ml HNO3 + 50 ml H2O. These were then used for optical microscopy. The micro hardness measurements were taken on the cross section perpendicular to the welding direction using an indenter with a load of 588N. To evaluate the mechanical properties standard tensile specimens were fabricated in a direction perpendicular to the welding direction having a gauge length of 50 mm.

3. RESULTS AND DISCUSSION

3.1. Visual Inspection
The result of FSW with welding method has a flat surface and smooth. On the surface there are grooves due to shifting tool, the width of the flow arm depends on the diameter of the shoulder. To ensure the weld is good or not by observing the back of the weld, when the parts are perfect together means that the welds were perfect together. At the end of the welding process there is a hole due to the probe, the hole was formed because at the end of the welding had no part of which is processed so that the welding material is not closed. The surface in contact with the tool shoulder (Figure 2-a) is characterized by the presence of semicircular features, similar to those induced by a conventional milling process. The opposite surface (Figure 2-b) doesn’t show evident surface modification induced by the FSW process.

(a) Figure 2. The Surface in Contact with the Tool Shoulder (a) and Opposite Side (b)

3.2. Microstructure Evaluation
Optical micrographs showing the stir (nugget) zone are shown in Figure 3. The optical micrographs of observation done with Metal Olympus Microscope with a magnification of 50X. In both materials, a different distribution of particles and a reduction in their size, due to the abrasive action of the hard tool, are evident. Changes in the steering microstructure zone (the part in direct contact with the probe and shoulder) is the effect of deformation at high temperature due to rotation and longitudinal movement of the probe and shoulder, causing the grains in the stir zone is smaller than the grains in the parent material.
The characteristics of the stir zone is a common occurrence several concentric circles that have been referred to as the structure of "onion rings" (a circle like an onion). TMAZ occurs in the stir zone. In this section, voltage and temperature lower than the stir zone so that the effects of welding on the micro structure is smaller. Microstructure is the composition of the parent material, although a significantly deformation and rotation. TMAZ term used to describe any parts that have heating but not yet closed by the stir zone and flow arm. Phase that may occur in alloys 6xxx series is α-phase Al12Fe3Si; β-Al9Fe2Si2 [2]. Stirred region (nuggets) which is the region forging (forging) due to rotation and longitudinal movement of the probe as well as vertical.

3.3. Hardness Test
Standards used in hardness testing is ASTM E384-69. The purpose of testing this hardness is to know how big influence on the value of hardness in the area of welding along the weld, HAZ and base metal. Figure4. showed that the weld region and HAZ on welding aluminum 6110 by FSW method a significant decrease compared to the parent material of weld metal. The softening process is more clearly seen in the influence of heat (heat affected zone) is the edge of the welding area [1].

Decline in value of hardness occurred at a distance of 6 mm from the weld center, but on average at the center point of welding there is an increase of hardness, but insignificant. Furthermore, at a distance of 6-12 mm from the weld center of hardness began to increase in value occurs until the value is roughly equal to the parent material. Decline in value of hardness seen in the area of welding.

3.4. Tensile Test
Dimensions of tensile test specimens for welding materials using ASTM E6-69. Table1. shows that the largest tensile strength in the welded on the feed rate 320 mm / min that is equal to 8.86MPa with a strain of 2.17%. Material alloy Al-Mg-Si welded using the same weld metal bead will cause longitudinal cracks[3]. Increase the feed rate will cause a decrease in heat input (heat input) and the relative would reduce the HAZ boundary of the material. FSW weld tensile strength was also influenced by the welding speed (feed rate / travel speed [1].
4. CONCLUSION
1. Occurred a significant decline in the value of hardness in the region of weld metal, HAZ and base metal of the parent material, but for variable 320 mm / min occurred narrowing the weld area. Value of raw material hardness is ± 55 VHN and the weld center ± 37.5 VHN.
2. Among the variables that have been investigated, stress and strain values is best on variable feed rate 320 mm/min (8.8Mpa with 2.17% strain).
3. Micro structure in the area of welding and parent material is essentially unchanged, but on the TMAZ grain is distorted so that looks like onion rings.

ACKNOWLEDGEMENT
Research sponsored by Research Institute, Institute of Science and Technology of AKPRIND Yogyakarta.

REFERENCES

Table 1. Tensile Properties of FSW

<table>
<thead>
<tr>
<th>Tool Feed rate (mm/min)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>320</td>
<td>8.86</td>
<td>2.17</td>
</tr>
<tr>
<td>200</td>
<td>6.37</td>
<td>1.02</td>
</tr>
<tr>
<td>93</td>
<td>7.17</td>
<td>1.63</td>
</tr>
<tr>
<td>64</td>
<td>5.75</td>
<td>1.84</td>
</tr>
<tr>
<td>40</td>
<td>7.23</td>
<td>1.63</td>
</tr>
</tbody>
</table>