Experimental Study and Optimization of Friction Stir Welding of Dissimilar Aluminum Alloys AA6101- AA1200

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Abstract - Friction stir welding (FSW) is a novel solid state welding process in which the weld is completed without molten metal. This is an environment friendly process with high potential and proven method for welding high strength aluminum alloys. Today’s manufacturing trend is to achieve the desired properties of material and to reduce the cost of production. Use of low price material and sometime dissimilar alloys are also used for cost reduction. It is very difficult to join dissimilar alloys than joining similar alloys due to the difference of their compositions. The goal of this research work can be broadly be stated as to present a systematic approach in Modeling, Characterizing and optimizing the process parameters of friction stir welding for joining dissimilar alloys AA6101/AA1200 and optimizing, using Taguchi method.

Key words : FSW, Aluminum alloys, Tensile strength, Taguchi method,

INTRODUCTION
Friction stir Welding (FSW) is a revolutionary solid state welding technique invented in 1991 at The Welding Institute (TWI). The process operates below the solidus temperature of the metals being joined hence no melting takes place during the process. This process is being used for plate fabrication .Friction Stir Welding is a hot shear joining process in which a non-consumable, rotating tool plunges into a rigidly clamped work-piece and move along the joint to be welded. The cylindrical rotating tool used in FSW has threaded/ unthreaded pin slightly less in length than the weld depth. The operating principle of FSW process is presented below.

Friction Stir Welding Process :
A rotating tool specially designed for the purpose to generate heat and material close to the tool is converted to super plastic nature. Then the tool is moved along the joint interface. The tool usually has a large diameter shoulder and a smaller threaded pin. The rotating tool develops frictional heating causing a thin plasticized zone around the pin and material is transported from front to the rear by a solid state key hole effect. The process is thus characterized by high strain rates and super plasticity near the rotating tool. This paper describe the process, and its effect on the parent metal as well as heat generation and thermal analysis its uses in various fields of engineering.

Fig: 1 Schematic diagram of Welding process
Fig:2 Cross section of Friction stir welding zone

Thermo-mechanical characterization of aluminum and its alloys have been produced over a period of time. Al-Mg-Si alloys (AA6xxx series) present an attractive properties with respect to high strength, welding performance, good corrosion resistance. These alloys are used in aircraft industries, automobile industries etc. Even though lot of
research work are being done on several 6XXX grade of material but none explored AA6101 and AA6101/AA1200. Use of low price material and sometime dissimilar alloys are also used for cost reduction. It is very difficult to join dissimilar alloys than joining similar alloys due to the difference of their compositions. Joining of these alloys have very prospective market for Gas cylinders, Battery car body and structures, ladders, trolleys, domestic and office furniture etc. These are generally done by the small entrepreneurs. Further study will proves its applicability in real life. Keeping all these points in mind, the present investigation was carried out.

Chemical Composition:

<table>
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<th></th>
<th>Copper</th>
<th>Magnesium</th>
<th>Silicon</th>
<th>Iron</th>
<th>Manganese</th>
<th>Chromium</th>
<th>Other Elements</th>
<th>Yield %</th>
<th>Toughness</th>
<th>Brinell hardness</th>
<th>Friction</th>
<th>Specific heat</th>
<th>Conductivity</th>
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<tbody>
<tr>
<td>AA6101</td>
<td>0.9</td>
<td>0.7</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>34</td>
<td>29</td>
<td>110</td>
<td>40</td>
<td>400</td>
<td>170</td>
</tr>
<tr>
<td>AA1200</td>
<td>0.32</td>
<td>-</td>
<td>0.1</td>
<td>0.6</td>
<td>0.1</td>
<td></td>
<td>0.1</td>
<td>31</td>
<td>23</td>
<td>120</td>
<td>40</td>
<td>200</td>
<td>120</td>
</tr>
</tbody>
</table>

Mechanical Properties:

 Experimental Study:
The machine used for friction stir welding was a conventional vertical milling machine which was transformed into a friction stir welding machine by designing a fixture that makes the milling machine capable of performing friction stir welding. The fixture was fitted on the milling machine table to do the friction stir welding. The tool used for welding was designed to fit the taper of the vertical head of the milling machine and clamped rigidly with a nut at the other end. The tool has a shoulder diameter 18 mm and cylindrical probe of 6 mm diameter. Friction stir welding was done by holding the plates to be welded securely in the fixture designed so that the plates stay in place and do not fly away due to the rotation of the tool. The plates were additionally secured with taper wedge to firmly hold the job on the fixture.

The rotational motion of the spindle was started and the tool is then got in contact with the surface of the plates and the probe is plunged at the butt welded zone to a depth so that the shoulder of the tool is firmly in contact with the plate to be welded. The vertical force is applied at predetermined amount. The tool is given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced, this time is called dwell time, and after the dwell time the tool is given forward motion which formed the weld. The tool is withdrawn after the weld is fabricated, the process leaves a hole and the design of the weld is done in such a way that the part with the hole in it is cut and not used for the further processes with the welded plates. Efforts are on the way so that the hole can be avoided at the end.

RESULTS AND DISCUSSION:

Temperature measurements were carried out during the FSW of the AA1200- AA6101-T6 joints. The assumptions regarding the approach of the thermal cycles in the HAZ/TMAZ interface and SZ, as mentioned were also assumed for the AA1200-AA6101-T6 joints, as well as considerations associated with the accuracy of the temperature measurements. The thermal history measured for the dissimilar AA1200- AA6101-T6 joints are shown in the Table -3

Temperature Distribution on surface of joined plate
The peak temperature measured for the AA6101-T6 joints at different position. It is seen that it took 5 seconds to reach maximum temperature and cooling down to 50°C took about 78 seconds. Observation shows that maximum temperature is held at 9 mm from the weld line.

Tensile Test of Dissimilar Al-Alloys AA1200 - AA6101-T6
Transverse tensile specimens were tested in order to determine the tensile properties at room temperature for the dissimilar joints of Al-alloys AA1200 and AA6101-T6 alloy base metals by the FSW process, for different energy inputs applied. Following the same procedure used earlier, specimens are obtained from the butt joined plates of two different base metals along the same direction, with the testing load position transverse to the welding direction and rolling direction. The tensile properties for the nine welding conditions studied. Test results are given in the following table for both UTS and % elongation.
The results show that high heat input gives better weld performance. This may be explained as at high heat input the weld interface is more plasticized. At high energy input level amount of strain energy develops at low level due to more plasticity of the material. At low energy input low rpm of the tool is unable to develop sufficient strain energy. This results lower welding efficiency. It is important to remark that fracture occurs in the retreating side and location close to the interface TMAZ/HAZ. The shift in failure location is basically to the stretching of the temperature gradient with the energy inputs. In this way critical temperature field shifts towards the base material AA1200 away from the SZ. In addition, it is reported for a friction stir welding that fracture never occurred close to the original joint line, but mostly near the line where shoulder of the tool had touched the top side of the weld at 45° fracture, at the bottom side of the weld.

It also may be noted that UTS is around 78% its base metal of lower strength of material. This may be explained as while welding the AA1200 was placed at the retreating side. Aluminum alloy AA6101 contains 0.7% Mg while AA1200 contains trace amounts of alloying elements. Hence, a study of FSW of these two alloys provides an excellent way to determine the nature of solute transport, which in turn is related to the plastic flow. Concentration profiles of Mg across the weld provides important insight about the nature of plastic flow and mixing of magnesium between the two alloys. The transport and mixing of Magnesium from Mg-rich AA6101 alloy into very low alloy containing AA1200 did not occur in the atomic level and the spatial variation of concentration profile between the two plates. The computed magnesium concentration profile based on its transport by convection and diffusion showed a gradual decrease of Mg in AA6101 to very small concentration in AA1200. Imperfect mixing of plasticized alloys during FSW where the materials seem to move in layers without significant diffusive interlayer mixing.

**Hardness Test:**

Hardness profiles are determined along the transversal cross section surface of the AA1200 and AA6101 dissimilar FSW joints for different conditions. Hardness measured transverse to the weld direction of dissimilar FSW joints produced with different conditions along three different lines i.e. near the starting point, middle of the length and lastly near the end point. Hardness also measured on both the sides of the weld i.e. AA6101 on advancing side and AA1200 on retreating side of the weld. The hardness is plotted as shown in the fig- 4 AA6101 & AA1200.
Optimization of Process Parameters:
There are quite a few methods for optimization.
1. Taguchi Method,
2. ANOVA Method,
Taguchi & ANOVA methods can be performed best by MINITAB or DOE software.

Every experimenter has to plan and conduct experiments to obtain enough and relevant data so that he can infer the science behind the observed phenomenon. He can do so by,

i) Trial-and-error approach:

Design of experiments method is used where a well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources required are prohibitively large.

Taguchi Method:
Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters to obtain BEST results. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi’s Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Taguchi Analysis of Trial 1, Trial 2, Trial 3 versus Rotational speed, Axial Force, Welding Speed are plotted in graph and shown below.

Predictions from Taguchi Analysis for AA-6101 T-6 and AA-1200:

The Optimum combination of parameters obtained from the main effect plot for the S/N ratio and mean with the best combination at 250 rpm Rotational Speed, 10 KN Axial Force and 18 mm/min Welding Speed and the Optimized Tensile Strength has been predicted as 80.05 MPa.

CONCLUSION:
Different process parameters were applied for welding dissimilar alloy AA6101 and AA1200 which is almost pure Aluminum. The results ie welding strength and % elongation is matching with the performances expected in case of AA6101. It is interesting to find that welding performance of dissimilar alloys are much lower than welding performance of AA6101 and higher than AA1200. During welding this set dissimilar alloys AA6101 is placed on the advancing side and during the process of welding some Magnesium are being transferred to retreating side from the advancing side resulting a Magnesium rich alloy in the retreating side. Due to this phenomenon welding performance is slightly improved than AA1200 on the Retreating side.
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