Studies on post weld heat treatment of dissimilar aluminum alloys by laser beam welding technique

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Abstract. The present study mainly focuses on post weld heat treatment (PWHT) of AA5083 and AA6061 alloys by joining these using laser beam welding at three different laser power and two different beam spot sizes and three different welding speeds. Effects of these parameters on microstructural and mechanical properties like hardness, tensile strength were studied at PWHT condition and significant changes had been observed. The PWHT used was artificial aging technique. The microstructural observations revealed that there was appreciable changes were taken place in the grain size. The microhardness observations proven that the change in the hardness profile in AA6061 was appreciable than in the AA5083. The tensile strength of 246 MPa was recorded as highest. The fractured surfaces observed are predominantly ductile in nature.

1. Introduction

In the present scenario, in the automotive and shipbuilding sectors the usage of aluminium and its alloys are increasing at a rapid speed due to its light weight, high strength to weight ratio, formability and recyclability [1]. Conventional joining of these dissimilar alloys is a challenging task due to susceptibility of hot cracking, higher thermal conductivity and high porosity [2-4]. To avoid above problems, laser beam welding is a promising technique because of its advantages over the conventional joining process with the characteristics like low heat input, high power density, high welding speed, narrow heat-affected zone (HAZ), higher depth-to-width ratio of the bead and low distortion. The process provides the complete protection of shielding gas to the weld pool [5-8]. In general solid state welding techniques were contemplated to avoid these problems between dissimilar joining of various materials using different processes [9-18]. Usually, after welding the change in properties takes over base metals resulting lack of strength in these alloys. In order to compensate this, heat treatment is a necessary technique to obtain the required weld properties and in some cases to relieve the residual stresses which affects the weld strength.
Based on the previous results, our present study mainly focusing on the post weld heat treatment of dissimilar welding of AA5083 and AA6061 for the automobile application by laser beam welding process. The welded joints were thoroughly studied after PWHT a kind of changes happens in microstructures in compatible with mechanical properties for all welding conditions. The fractography analysis was done to investigate the joints mode of failure.

2. Experimental Procedure
The surface was cleaned with acetone to clean dirt, surface oxides and any contaminants prior to laser welding. The laser beam welded joints were made with a butt joint configuration was shown in figure 1. Proper clamping was done to avoid joint distortion with suitable clamps. Nd-YAG laser welding equipment used at beam sizes of 180 μm and 360 μm in a continuous mode. The shielding gas used for the present study is high purity (100%) helium gas with a flow rate of 25 l/min. Extensive preliminary welding study was carried to find the optimal welding conditions to get the sound weld. Keyhole technique was imposed to get the full depth of penetration. The chemical composition, welding conditions and process parameters were represented in Table 1 and Table 2. The influence of post weld heat treatment was studied on the welded joints by heating the joints to 175°C for a time period of 8 hours. The studies are proved that aging can be done to the AA5083 alloy at 150°C for 24 hrs. This aging concept is adopted because to remove the small amount of residual stresses in AA5083 and to improve the strength in the AA6061 by forming the precipitates in the weldment.

The equipment used for the heating the joints was induction furnace which was heated up to the required heating temperature i.e.,175°C. After completing the PWHT process the samples were cooled to room temperature within the furnace. For microscopical studies the samples were cut and mounted it with a flat surface than polishing was done on the mounted samples. After polishing the samples were etched with poulton’s reagent and CETI stereo zoom microscope was used for observing the microstructures. The Zwick microhardness tester was used to measure the hardness values across the weldment through weld region, heat affected zone and base metal with an interval of 0.2 mm at 0.3 kg load for 15 sec. The tensile test was carried out in the Hounsfield tensometer and the standard used for it was ASTM E8M.

![Figure 1 Schematic view of the square butt joint configuration](image)
Table 1 Elements and its composition of the substrates used for this study

| Elements     | Si  | Fe  | Cu  | Mn  | Mg  | Cr  | Zn  | Ti  | Al  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| AA5083-H111  | 0.12| 0.33| 0.03| 0.51| 4.39| 0.08| 0.01| 0.02| balance |
| AA6061-T6    | 0.478| 0.46| -   | 0.986| 0.855| 0.035| -   | -   | balance |

Table 2 Experimental conditions

| Weld number | Beam spot size (µm) | Laser Power used (kW) | Rate of welding (mmin⁻¹) |
|-------------|---------------------|------------------------|--------------------------|
| 1           | 180                 | 3                      | 2                        |
| 2           | 360                 | 3                      | 2                        |
| 3           | 180                 | 3.5                    | 3                        |
| 4           | 360                 | 3.5                    | 3                        |
| 5           | 180                 | 3.5                    | 3.5                      |
| 6           | 360                 | 3.5                    | 3.5                      |

3. Results and Discussions

3.1 Microstructural studies

For microstructural analysis in PWHT samples are prepared as in the above condition. From figure 2, it was clear that after PWHT the high amount of change in the grain sizes were observed in the weld region. The coarsening grain size is observed in the AA6061 side and there is no significant change in AA5083 side. This may be due to during PWHT coarsening of grains and precipitate formation may also take place in the weld region. In figure 2 (a) & (b), at the top of the weld finer grain structure is observed and in bottom coarse grain structure is observed. It is due to solidification changes during welding and cooling, at the top of the weldment cooling rates are high resulting in refining the grain sizes finer and in the bottom cooling rates will be low results in coarse grain structure is formed. And at center of weld region more grain coarsening is not observed. It may be during welding the precipitate particles are totally dissolved. Balasubramanian et al. [19], have been observed that after PWHT, precipitation formation is uniform in the pulsed current. The distribution of the precipitates are evenly dispersed in the weld region. The precipitate formation was dense at the grain boundaries than the interior region of the grains in the constant current weldments. In the present study, continuous mode of laser welding also has not shown any effect on precipitate formation due to during welding the dissolved particles will not show any effect during PWHT. Figure 2 (c) & (d) showing the optical microstructure at AA5083 and AA6061 sides. The change in microstructure is observed when compares with as-welded condition, and AA6061 side grain coarsening taken place which is due to PWHT.

3.2 Microhardness results

Figure 3 showing the microhardness profiles at different conditions in PWHT. The results are showing that slight variation is observed in the PWHT conditioned weldments. The base metal hardness of AA6061 is increased since it is an age hardenable alloy and the hardness reported as 96±3 Hv. Interestingly, recovery has taken place in AA5083 side and hardness reported as 82±3 Hv. Previous studies [20,21] reported that for AA5083 at 150 °C for 24 hours, aging phenomena will takes place, reveal the microstructures by decorating the grain boundary with precipitates may be due to that reason.
increase in hardness in AA5083 base alloy has been taken place. And in weld zone sufficient recovery has not taken place [22-24]. In weld zone 5 to 9 Hv improvement is observed after PWHT compares with as-welded condition. Nearly 30 Hv recoveries have been taken place in the AA6061 side. In weld zone the reason for that slight increase is may be due to dissolved Si has recovered during PWHT.
3.3 Tensile test results

The tensile test results are shown in following Table 3. PWHT shown a remarkable changes in the lower power rate and welding speeds (3 kW, 2 m/min, 180 µm and 3 kW, 2 m/min, 360 µm). During the tensile test the weld region reaches the plastic zone and which is limited to certain extent. Also, it is noted that after reaching the plastic zone in weld region, the plasticity continues to improve in the weld region and base materials. During the test the material undergoes the high amount of stress in tri axial direction which is difficult to reduce. Due to this, the crack extension was very less results in lowering the tensile strength. In either of the direction, if the tensile strength is higher the plasticity can goes into the parent material as the deformation can takes place in weld region as well in base materials. The triaxial stress can be easily reduced, due to that the amount of force which was required to make the crack was high and resistance offered by the weldment is also high which resulting the higher tensile strength. The increase in the tensile strength of the weldments after PWHT was because of the above reason.

Here highest tensile strength was reported at (3 kW, 2 mmin⁻¹, 180 µm) weldment. The percentage of elongation is increased in the PWHT condition due to grain coarsening which decreases the space between the grains. The fracture was observed in the weld region of AA6061 side, after PWHT recovery has not been taken place in the AA6061 weld region due to laser welding dissolves the strengthening precipitates which will not recover after PWHT also. After PWHT the joint efficiency is increased to 77% and 85% corresponding with AA6061 and AA5083.

Table 3 Tensile test results of weldments in PWHT condition

| Condition | Yield strength (MPa) | Ultimate tensile strength (MPa) | % of Elongation | Strain hardening exponent (n) | Strength coefficient, K (MPa) |
|-----------|----------------------|-------------------------------|----------------|-----------------------------|-----------------------------|
| 1         | 185                  | 241                           | 11             | 0.21                        | 360                         |
| 2         | 177                  | 229                           | 7              | 0.22                        | 363                         |
| 3         | 194                  | 238                           | 8              | 0.19                        | 333                         |
| 4         | 181                  | 239                           | 8              | 0.16                        | 365                         |
| 5         | 193                  | 246                           | 9              | 0.17                        | 352                         |
| 6         | 160                  | 217                           | 7              | 0.17                        | 297                         |
| 7         | 169                  | 223                           | 8              | 0.19                        | 321                         |
| 8         | 152                  | 202                           | 9              | 0.15                        | 224                         |
| 9         | 161                  | 211                           | 8              | 0.16                        | 281                         |

![Fracture](image_url)

Figure 4 Typical failed specimen in fusion zone of AA6061-3.5 kW, 3.5 m/min, 180 µm.
The failed tensile tested specimen was shown in figure 4. SEM photographs were captured from the tested specimens in the centre region shown in figure 5 and 6. In PWHT, the fracture regions are clearer than in as-welded condition. The dimples can be observed in the failure surface and the mode of fracture is in ductile. And porosity also can be seen from the figure 5, the finer dimples are observed than in 360 µm even after PWHT. In this the dimples seems to be equiaxed in both figure 5 and figure 6. It may be due to PWHT, grain refinement will takes place resulted in equiaxed dimples. The size and shape of the dimples are unstable and better results are achieved after PWHT than in as-welded condition.

![Image of failure surface at 3.5 kW, 3.5 mmin⁻¹, 360 µm](image1)

![Image of failure surface at 3.5 kW, 3.5 mmin⁻¹, 180 µm](image2)

**Figure 5 Image of failure surface at 3.5 kW, 3.5 mmin⁻¹, 360 µm**

**Figure 6 Image of failure surface at 3.5 kW, 3.5 mmin⁻¹, 180 µm**

### 4. Conclusions

The effect of the LBW dissimilar welds (AA5083 and AA6061) in PWHT were studied and summarized as,

1. Dissimilar welding of AA5083 and AA6061 was successfully welded by using LBW technique.
2. At weld fusion line, columnar grains were observed due to thermal changes during solidification. The columnar grains became equiaxed when moving from fusion line to center line.
3. Grain refinement occurred after PWHT and an increase in mechanical properties were observed.
4. Post weld heat treatment helps the weldments in significant enhancement of hardness in weld region of AA6061 compared to AA5083.
5. At 3.5 kW power rate of laser, 3.5 mmin⁻¹ welding rate and 180 µm of spot size after PWHT, sufficient increase in strength in weldments is observed and a highest tensile strength (246 MPa).
6. PWHT conditions, fracture was taken place in the fusion zone of AA6061 and fracture observed on surface is predominantly ductile in nature.

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