INVESTIGATION OF HAZ SOFTENING OF AA6082-T6 AUTOMOTIVE ALUMINIUM ALLOY BY PHYSICAL SIMULATION

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ABSTRACT

The 6082 aluminium alloy is widely used for the automotive parts that work under the conditions of dynamic and cyclic stress, but the selection of proper production parameters is most challenging task to get excellent result. Physical simulation of HAZ helps in identifying suitable welding parameters like linear heat input, voltage, current etc. In this paper, the influence of weld heat cycle on heat affected zone (HAZ) is simulated for Tungsten Inert Gas Welding (TIG) using Gleeble 3500 thermomechanical simulator, automotive aluminium alloy (AA6082-T6) plate of thickness 1 mm. Investigation of HAZ softening were performed by means of hardness measurement on the simulated specimens. Different peak temperatures and linear heat input were selected, and physical simulation performed using Rykalin-2D model (thin plate). Experimental works included physical simulation and Vickers hardness tests.

Keywords: HAZ characteristics, Gleeble 3500 thermophysical simulator, automotive aluminium alloy AA6082-T6, Rykalin-2D model.

INTRODUCTION

Aluminium and its alloys are extensively utilized in many industries and have attracted the attention of many researchers, engineers and designers as promising structural materials for the automotive industry applications, where light weighted materials are appreciated for its ability to reduce the self-weight while maintain the acquired strength of large components[1]. However, welding changes the microstructure of these aluminium alloys due to the formation of heat affected zone [2].

In this study, the mechanical properties and HAZ softening of welded AA6082-T6 aluminium alloys are studied. The alloy is designating as a 6xxx-series of aluminium which have Mg and Si as the main alloying elements. The 6xxx-series aluminium alloys are, due to their good physical and chemical properties which includes low density, high strength, good weldability and corrosion resistance, widely used in structural industries [3][4]. The high strength aluminium alloys have much lower formability at room temperature than typical sheet steels [5], therefore the formability properties should be improved. There is also a potential for loss of alloying elements from the weld pool that may result in a reduction in strength. Magnesium has a low melting point and may be lost or oxidized during welding [6].

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The aims of this paper to conduct a series of experiments and understand the behaviours which make it possible to measure the objective data on the basis of the obtained image of the aluminium alloys tested with heat-affected zone tests in a physical simulator. Generally, welding defects commonly found in aluminium welded joints: oxide layer, hot cracking, HAZ softening and the toughness and/or strength reduction in HAZ [7]. Greater care is required when welding aluminium, especially control of weld heat input there are limitations on the weld processes that are applicable. The TIG welding process has thus far been the most industrially accepted welding process for aluminium (Olsen, 2009).

The main objective is to achieve the weldability of AA6082-T6 alloys based on the welding parameters like heat input. Thermophysical simulation were carried out on Gleeble and microhardness tests performed.

EXPERIMENTAL METHODOLOGY

To implement the new process into a manufacturing environment, it must ensure that if the process is practical for its application, if the desired results can be achieved in terms of material properties, microstructure, etc. So, the detailed experimental methods were designed to investigate the weldability for AA6082-T6 alloy and also includes test facility design, descriptions and test sample preparation. The experimental programme is divided into two main parts; the first is thermal testing, which is used to investigate the effect of the heat cycle on the post weld strength of AA6082. The second is the hardness test in the HAZ, which is carried out to investigate the effect of welding parameters (heating energy) on the mechanical properties of AA6082.

To investigate the weldability of the AA6082, tests were designed to simulate the material properties at different peak temperatures using the Gleeble 3500 simulator. During the experimental work, HAZ tests have been performed in a new generation thermophysical simulator, called Gleeble 3500, installed in the Institute of Materials Science and Technology of the University of Miskolc. By the equipment the desired HAZ area can be precisely and homogeneously simulated in a volume sufficient for the further material tests. Finally, microhardness tests were performed on Mitutoyo micro hardness tester to determine the HAZ characteristics.

Investigated material

Aluminium–magnesium–silicon (Al–Mg–Si) denoted as 6XXX series alloys are medium strength heat treatable alloys and have excellent formability from simple to complex profiles by extrusion and good corrosion resistance characteristics. Mg and Si are the major solutes they increase the strength of the alloy by precipitation hardening. There has been a considerable industrial interest in these alloys because two-thirds of all extruded products are made of aluminium and 90 % of those are made from 6XXX series alloys [8]. In this series, aluminium alloys the AA6082-T6 sheet with thickness of 1 mm was chosen for our experimental investigations. The investigated AA6082 alloy is applied in the structural elements of modern premium cars such as BMW 6, Ferrari 548 Italia, Jaguar XJ, Range Rover etc [4]. This base
material includes mainly magnesium and silicon as alloying elements, and its strength can be increased with annealing hardening. The relatively high strength is derived mainly from the finely dispersed Mg$_2$Si precipitates both within grains and along grain boundaries. The base material chemical composition shown in Table 1, and the mechanical properties are shown in Table 2. The T6 condition means, that this aluminium base material has a homogenizing solution annealing at 535 °C for 30 min, then quenching, and finally aging at 190 °C for 8 hours.

Table 1  
Chemical composition of AA6082-T6 aluminium alloy (wt%).

<table>
<thead>
<tr>
<th></th>
<th>Mg</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Fe</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.70</td>
<td>0.90</td>
<td>0.40</td>
<td>0.09</td>
<td>0.02</td>
<td>0.08</td>
<td>0.03</td>
<td>0.46</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Table 2  
Mechanical properties of AA6082-T6 aluminium alloy.

<table>
<thead>
<tr>
<th>Density (g/cm$^3$)</th>
<th>Melting point (liquidus)(°C)</th>
<th>R$_m$, MPa</th>
<th>R$_{p0.2}$, MPa</th>
<th>A$_{50}$, %</th>
</tr>
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<tbody>
<tr>
<td>2.7</td>
<td>600</td>
<td>280</td>
<td>315</td>
<td>12</td>
</tr>
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Heat source model

In the QuickSim software developed for Gleeble programming the possible HAZ simulation welding heat cycle models [9] are F (s, d) thermocouple measurement or FEM, Hannerz, Rykal-2D, Rykal-3D, Rosenthal, Exponential. But in this paper, heat cycles were determined according to the Rykal 2D model. This model describes the temperature field generated by a moving spot-like heat source on the surface of a semi infinity body. In the sheet metals the characteristic roll of heat conduction disappears and the roll of convection is getting more important due to the larger surface to volume ratio. By the application of Rykal 2D model the time-temperature points of HAZ heat cycle can be calculated as follows [10]:

\[
T - T_0 = \frac{a}{\sqrt{b^* (t - t_0)}} \exp \left(\frac{c}{t - t_0}\right)
\]  

\(a = \frac{Q}{d}\)  

\(b = 4\pi k^* c^* \rho\)  

\(c = -\frac{r^2}{4k^* (c^* \rho)}\)  

\(Q = \sqrt{\frac{4\pi k c^* \rho \Delta t}{1/(T_z - T_0)^2 - 1/(T_1 - T_0)^2}}\)
where:

\[ Q = \text{energy input, J/cm} \]
\[ c = \text{specific heat, J/g/°C} \]
\[ r = \text{density; g/cm}^3 \]
\[ k = \text{thermal conductivity, W/cm/°C} \]
\[ d = \text{plate thickness, cm} \]
\[ d_e = \text{equivalent plate thickness, cm} \]
\[ T_1, T_2 = \text{temperature used to define cooling time, °C} \]
\[ t_0 = \text{time at the end of preheating, s} \]
\[ \Delta t = \text{cooling time from } T_2 \text{ to } T_1, \text{s.} \]

Experimental procedure

The aluminium sheet which are used for thermomechanical testing using Gleeble 3500 simulator are short samples. The samples were cut into the dimension 70 x 10 x 1 mm, was machined from the supplied sheet in a T6 condition. The geometry of the samples is shown in Figure 1. AA6082-T6 is a locally available material with medium strength (yield strength \( R_{p0.2} = 250 \text{ MPa} \)) [11].

![Sample dimensions](image)

A precise preparation of HAZ specimen with required geometrical shape and good surface quality is indispensable for the successful simulation. A K(NiCr-Ni) type thermocouple was welded onto the middle of sample for temperature record as shown in Figures 2(a) and 2(b) respectively.

The HAZ tests were carried out on Gleeble 3500 thermomechanical physical simulator, installed in the Institute of Materials Science and Technology of the University of Miskolc, Hungary which is capable for the reproduction of real material processing (e.g. welding, heat treating and metal forming) in laboratory circumstances as shown in Figure 3. Although it must be remarked that the heating and cooling rate are always the function of specimen size and shape and in many cases external cooling is needed for the desired cooling rate. In first case, the specimen was simulated at four selected peak temperature i.e. 550 °C, 440 °C, 380
°C and 280 °C using a linear heat input energy of 100 J/mm and in second case same peak temperature with linear heat input energy of 200 J/mm.

Figure 2.
(a) thermocouple welding machine and (b) thermocouple welded on the sample

Fig. 3
Test device- Gleeble 3500 simulator system.

The heating rate, holding time, cooling time of the thermal cycle parameters were automatically adjusted according to the given plate thickness, energy input and possible procedures during the tungsten inert gas welding.

Fig. 4 Thermal cycles
(a) linear energy = 100 J/mm and (b) linear energy= 200 J/mm
The peak temperature, heat input and holding time of the HAZ thermal cycle parameters were selected according to the possible procedures during the Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG). Heat cycles were determined according to the Rykalin 2D model. The programmed and realized HAZ thermal cycles for the two technological variants 100 J/mm and 200 J/mm as shown in Figures 4(a) and 4(b) respectively.

RESULT AND DISCUSSION

Hardness test

A Mitutoyo MVK-H1 Microhardness Tester was used for the hardness examination which contains all standard hardness testing methods between 10 g–1 kg as shown in Figure 5(a), has an XY stage and magnifications of 100x and 400x. The measurement of the hardness is done on five points on the surface of the cross section at HV0.2 loading. Four points for each corner of the surface and one point in the middle of cross section, precisely beside the mark of the thermocouple as shown in Figure 5(b).

![Fig. 5 Hardness test](image)
(a) Mitutoyo micro hardness tester and (b) hardness measurement pattern on the sample

The measured hardness of the base material approximately 107 HV0.2. The BM has the maximum amount of precipitate of phase and therefore has the maximum strength but with the lowest ductility. According to the hardness tests we can conclude that in case of the lower heat input the AA6082 T6 followed the safety value required by EN ISO 15614-2 standard which provide welding procedure test for arc welding of aluminium and its alloy is above the 60 % of the base material strength and is considered as safe for the welded joint with tempered condition T6 and post weld condition as natural ageing. Indeed, the results values were above the minimum hardness value 64 HV0.2 as shown in the diagrams on the Figures 6 (a).
The microhardness in the HAZ provided a convenient and simple means of studying the effect of heat input during welding on strength. We can see that in Figure 6 (a) all hardness value for linear heat input 100 J/mm lies above the minimum limit calculated for HAZ which is considered as good result and following the safety limit. But from Figure 6 (b), we can conclude that with the increase of linear heat input i.e. 200 J/mm at peak temperature 440 °C is under the control limit and not conforming to safety limit prescribed by the standard. Microhardness varies at a range of 64 HV to 100 HV from weld center to parent metal. Also, it was observed that the fall in microhardness moves away from weld center. This shows clearly the effect of heat input on microhardness.

So, the Figure shows that with an increase of the heat input, the grains both in the fusion zone and the HAZ were coarsen and the width of the HAZ was increased for TIG welded Al 6082 alloy plates.

CONCLUSIONS

The Rykalin 2D heat cycle was suitable related to the thickness 1 mm and was programmed with Quicksim software of Gleeble 3500 physical simulator. The reproduction of heat affected zone areas were successfully performed by the Gleeble 3500 physical simulator. Two technological variants (Q = 100 J/mm and 200 J/mm, linear heat input energy) and four peak temperatures 280 °C, 380 °C, 440 °C & 550 °C. According to the EN ISO 15614-2 standard, hardness tests performed in HAZ areas fulfilled the minimum allowed 64 HV0.2 hardness for linear heat input 100 J/mm but for higher heat input like 200 J/mm is not conforming to safety limit. High heat input generates wider weld zone and HAZ, which reduces the joint strength and weld hardness. There was significant softening noticed in HAZ at the high heat input 200 J/mm. A little softening was noticed at the low heat input 100 J/mm and that was remarkable at the higher temperatures (440 °C and 550 °C). The decay of strength in weld HAZ was due to the precipitation and coarsening β phase. In weld HAZ, the region of peak temperature 440 °C where containing the most precipitate of β phase had the lowest strength. The microstructural changes that lead to loss of hardening and thereby mechanical strength in the HAZ of heat treatable aluminium.
alloys is a well-recognized issue that has to be taken into account when designing welded structural components. The physical simulation procedures allow studying materials behaviour at conditions very close to real industrial processing or applications, and by means of physical simulation a large variety of microstructures and associated mechanical properties can be obtained and studied in a short time and for a tiny fraction of full-scale industrial experiments.

REFERENCES


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