Development of rapid heat solid solution process of Al 7075-T6 alloy applying near-infrared ray heater

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Abstract. To improve the formability and productivity in cold forming of aluminum alloy, w-temper forming process was developed. In this process, the T6-temper blank is subjected to the solution heat treatment (SHT) and then quenched to achieve the w-temper. At present, the main problem of this process is that too long SHT time cannot meet the manufacturing cost. For example, the quenching time is 10 sec, while the SHT time is 30 min. In this paper, rapid solid solution of Al 7075-T6 alloy sheet was implemented in near-infrared ray(IR) heater. Applying IR, contact heater was developed instead of the traditional heater using cartridge heater. The results have shown that it is possible to accurately control the sheet temperature for solid solution temperature in short time. Also, compared to SHT using traditional heater, the rapidly heating using IR heater could make the mechanical properties of w-temper.

1. Introduction

Global warming is a serious concern where it is driven in part by the exhaust gases from automotive vehicles. For both fuel economy and emissions control, reducing the weight of car bodies has been a focused issue in the automotive industry [1-3]. For weight reduction, Al7xxx alloys have attracted much attention from the automotive industry due to its superior specific strength compared to ultrahigh-strength steel (UHSS). But, a disadvantage with high-strength these alloys compared with UHSS is that the formability is low. In order to improve the formability and productivity in the cold forming of these alloys, a limited study has suggested the application of W-temper forming (WF).

In WF process, the T6-temper blank is subjected to the SHT and then quenched to achieve the w-temper. After that, the blank is transferred into the die and deformed at RT before the precipitation starts. At present, the main problem of this process is that too long solid solution time cannot meet the manufacturing cost. Several studies have demonstrated that the rapid heating of aluminum alloys is significantly influenced by short heating time. In practice, Xu, Xiaofeng et al. examined that heating speed by contact solid solution treatment show a critical influence on microstructure and mechanical properties of Al 7075-T6 alloy [4]. Maeno, Tomoyoshi et al. demonstrated that quick heating provides similar mechanical propertied and formability [5].

In this paper, the innovative heating methods in a contact IR heating was utilized to reduce the solid solution time of Al 7075 alloy sheets. First, a contact IR heater was designed and manufactured. And then the research on the rapid SHT of Al 7075 alloy by contact heating method was conducted.
2. Experiment
A commercial Al7075 alloy in T6 condition with a thickness of 2.0 mm has been used in this research, having the following chemical composition given in table 1. In order to simulate the WF process, Al 7075 alloy samples were solution heat treated in a contact IR heater for 150 sec at 475°C. Then, all the samples were quenched by a cold flat die. The WF process is schematically shown in Figure 1. Hardness test was conducted to observe the change in mechanical property in the alloy with different solid solution time. The measurements were operated using a HM-100 Vickers microhardness tester with a load of 100 gf and a dwell time of 12 sec.

Thermal analysis was carried out using the differential scanning calorimetry (DSC) system (TA-100, TA Instruments). High purity Al 99.9% was used as a reference material. The specimens were heated from 60 to 300 °C at a constant heating rate of 10 °C min⁻¹. The selected conditions of samples were prepared for the DSC testing to have thicknesses of ~0.6 mm with weights of ~20 mg.

Table 1. Chemical compositions of Al 7075 alloy (wt.%).

|   | Mg  | Zn  | Cu  | Si  | Fe  | Mn  | Ti  | Zr  | Cr  | V   | Etc. |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
|   | 2.39| 5.61| 1.36| 0.095| 0.18| 0.042| 0.032| 0.016| 0.2 | 0.011| 0.064 |

Figure 1. The schematic view about WF process

3. Results and discussion

3.1. Contact IR heater setup

IR heating has more advantages than traditional heating. However, due to the temperature accuracy of sheets during heating, there are some requirements for the design of contact IR heater such as excellent temperature uniformity, minimize overshoot with temperature controllers and heating time. On the basis of important points, a contact IR heater was designed, as shown in Figure 2(a). It consists of the upper IR heater and lower cartridge heaters. The upper was designed to rapidly heat on the sheets by the output power of the IR heater controlled by the PID control system (Figure 2(b)). The lower die was selected for copper because of its high thermal conductivity and designed to maintain the temperature uniformity of the sheets during the control IR heater by cartridge heaters. Spring loaded K-type thermocouple were installed inside the lower die between each of cartridge heaters feedback adjustment of temperature.
uniformity and minimizing overshoot of the sheets. Guide pins were arranged in the lower die to assist the placement of the sheets (Figure 2(c)). Finally, the contact IR heater did not need to be installed in the press and equipment was driven to open and close by the movement of the pneumatic cylinder. The sheets were placed on the lower die, and the heating is completed after the equipment is closed, as shown in Figure 2(d).

Figure 2. Contact IR heater
3.2. Measurement of temperature

The temperature evolution of the sample at 475 °C with a holding time of 150 sec is shown in Figure 3. The temperature-time curve can be divided into two stage. In the first stage, when the sample temperature increased to 475 °C, the heating rate was very fast, and the sample reached 475 °C within 90 sec. In the second stage, when the samples reach target temperature, under the controlling of PID control system, the temperature fluctuates up and down at 475°C and gradually stabilizes. The temperature of the sample is relatively uniform and the temperature difference is about 2 °C.

![Figure 3. The schematic view about WF process](image)

3.3. Effect of solid solution time

3.3.1. Result of Hardness

Before forming at room temperature, the samples require sufficient solid solution time. In order to study the effect of solid solution time, the hardness of the w-temper with different solid solution time was measured. Figure 4 shows the measurement of hardness for four different times, 90, 105, 120 and 150 sec. It can be seen that hardness has decreased compared with the as-received condition (T6 ≈ 178Hv). Also, all samples show the hardness of Hv ≈ 88 immediately after quenching. The decreased hardness with different solid solution times is attributed to microstructure immediately after quenching. It is implied that the dissolution of MgZn₂ precipitation occurred.
3.3.2. Result of DSC

Significance of solid solution time on the precipitation behavior was examined through the DSC analysis for WF capability on the Al 7075 alloy. It is well described that the precipitation sequence of Al 7xxx alloys is expressed as follows [6,7]: Super saturated Solid Solution → G.P. Zones (GPZs) → metastable η’ phase → stable η phase (MgZn2). The DSC curves of the WF samples measured at four different times, 90, 105, 120 and 150 sec after SHT are given in Figure 5. It was reported earlier through the DSC examinations that the first peak reaction (stage I) at ~200 °C corresponds to the formation of the GPZs, the following double exothermic reactions (stages II and III) at ~210 and ~230 °C are attributed to the formation of the η’ phase and the transformation of η’ into the η phase. All samples demonstrated that first peak reaction appears at approximately 95 °C, most likely due to the formation of GPZs. The GPZs peak could be detected at DSC curve, which means the soluble Al matrix were completely dissolved.
4. Conclusion
The effect of solid solution time on the hardness using of Al 7075 alloy using contact IR heater was investigated. The following conclusions can be drawn.
1. The results showed that contact IR heater could reach the target temperature in a short time and greatly shorten the solid solution time.
2. The mechanical property resulted in reduced hardness compared to as-received condition (T6) and it was similar in hardness to WF using traditional heater.
3. The measured solid solution time will be useful database for the amount of pre-strain and aging condition for WF.

5. References
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