Optimal thermal process parameters of hot stamping AA 6061

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Abstract. Hot stamping is a new technology developed to address the formability challenge of aluminum alloy by applying plastic deformation to the heated blank at the solution heat treatment temperature. The stamped panels gain high strength via the subsequent ageing treatment. The present paper is focused on the effect of the thermal aspects of the hot stamping process on the mechanical properties of the final formed parts. It is concluded that for AA 6061 the optimal solution heat treatment parameters are a temperature of 560 °C and a soaking time of 40 minutes, and sequent ageing should be performed at 180 °C for 6 hours. The maximum transfer time of the heated blank into the press to ensure the strong age hardening is 10 s. The low temperature could suppress the natural ageing of alloy.

Keywords: Hot stamping, heat treatment, aluminum alloy, mechanical properties, age hardening

1. Introduction

In recent years, with the increasing concern about energy crisis and environmental issues, the vehicle is increasingly demanded to reduce energy consumption and pollutant emission, and improve fuel efficiency. Many governments in the world have issued legislations to require automotive manufacturers and suppliers regarding automobile fuel efficiency and carbon dioxide emission limits. It has been assessed that a 10% weight reduction can achieve 1.9 to 8.2% in vehicle fuel savings, and the emissions of an internal combustion engine vehicle using fossil fuel can be reduced by about 0.08 g CO2/km per saved kilogram of weight [1]. Therefore, the lightweighting has become an important concept in the auto industry, and the use of an alternative energy source in the transportation sector is another inevitable trend in manufacturing vehicles. In order to achieve a longer driving distance, it is indispensable for electric vehicles to be equipped with larger batteries to store more energy. Therefore, for electric vehicles the lightweight demand is more urgent than that for conventional fossil fuel vehicles.

Automotive lightweighting is primarily achieved via the combination of structural optimization, lightweight material applications and advanced manufacturing techniques. Compared with other lightweight materials, such as ultra-high-strength steels, magnesium alloys and fiber-reinforced plastics, aluminum alloys are the best compromise between weight-saving potential and cost [2]. A handful of premium vehicles built in modest numbers have used aluminum alloys to make their bodies, while few mid-range vehicles can afford the high forming cost of aluminum alloys bodies [3]. It is due to the low
formability of aluminum alloys sheets, the low cost cold stamping can only be used to form parts with simple shapes, while for complex parts special forming methods, such as quick plastic forming technology [4], have to be applied, resulting in the increase of cost and time. Hot stamping is another new technology developed to address this formability challenge. This process chain mainly consists of solution heat treatment of the blank and transfer into the press, simultaneous forming and quenching in die, storage at room temperature and paint baking. It is therefore often called as HFQ technology [5]. The solution heat treatment destroys the desirable microstructure of original alloy sheets gained by heat treatments in sheets production factory. In order to recover or improve the mechanical properties of the formed parts, another heat treatment process is needed to follow the forming process except the paint baking. For example, to regain the T6-temper properties of AA 7075, the hot-stamped part was artificially aged at 120 °C for 24 hours [6]. Both the plastic deformation at elevated temperature and the thermal process parameters affect the mechanical properties of the final part formed via the hot stamping. This paper investigates the effect of the latter in order to optimize the process window for hot stamping.

2. Experimental

AA 6061-T6 sheet in the as-rolled condition with a thickness of 1.6 mm and chemical composition (in wt. %) of 0.72 Si, 0.5 Fe, 0.31 Cu, 0.13Mn, 1.0 Mg, 0.17 Cr, 0.13 Zn, 0.02 Ti, 0.01 V and rest Al was used in the current work. Tensile samples with a gauge length of 25 mm and width of 10 mm were cut from the sheet along the direction of rolling. Tensile tests were performed at room temperature at a constant strain rate of 1×10^{-3} s^{-1}. The Vickers hardness tests were performed with a force of 9.8 N and a holding time of 10 s. These two types of tests were repeated at least three times and eight times to ensure reproducibility, respectively.

3. Results and discussion

3.1. Effect of solution heat treatment parameters on mechanical properties

The Vickers hardness curves of AA 6061-T6 alloy after solution heat treatments at different temperatures and different soaking time are shown in Fig. 1. Fig. 1(a) shows the hardness test results of the alloy just after quenching in water, i.e. in W temper. The hardness is about HV 45 when the solution temperature is 480 °C, and about HV 50 when 500 °C. When the temperature increases to 520 °C, the hardness sharply increases to about HV 60. With the temperature continues to increase until 580 °C, the hardness shows weak increase. At all temperatures there are no obvious change of hardness with the soaking increase. Fig. 1(b) shows the hardness of the alloy after solution heat treatment and immediate artificial ageing at 180 °C for 6 hours. For solution heat treatment at 480 °C the hardness increment due to the artificial ageing is about HV 5–20, while for solution heat treatment at 500 °C the hardness increment increases to about HV 35–40. With the temperature continues to increase, the hardness shows increase until 560 °C. At 580 °C, the hardness decreases. The weak solution at low temperature results in the low hardness after ageing, while the grain growth at high temperature results in the restricted hardness increase after ageing. The hardness increases with the soaking time increasing until 40 minutes, and then shows weak change with the soaking time. Therefore, the optimal solution time is 40 minutes.

Fig. 2 shows the variation of post-ageing mechanical properties with solution heat treatment temperature under the same soaking time of 40 minutes. The yield strength and tensile strength reach the peak at the solution temperature of 560 °C. It follows the results of the hardness test. Therefore, the optimal solution temperature is 560 °C.
Fig 1. Vickers hardness curves of AA 6061-T6 alloy after solution heat treatment: (a) in W temper, and (b) after artificial ageing at 180 °C for 6 hours.

Fig 2. Variation of post-ageing mechanical properties with solution heat treatment temperature.
3.2. Effect of ageing parameters on mechanical properties
After one day delay at room temperature, the solution-treated tensile samples were aged at 180 °C for different time. The variation of yield strength and tensile strength with ageing time is shown in Fig. 3(a). The yield strength and tensile strength sharply increase until the ageing time reaches 6 hours, and then weakly fluctuate with the ageing time increasing. Fig. 3(b) shows the yield strength and tensile strength reach the peaks when the sample is aged at 180 °C for 6 hours. The optimal ageing temperature and time are 180 °C and 6 hours.

![Effect of ageing parameters on mechanical properties](image)

**Fig 3.** Effect of ageing parameters on mechanical properties: (a) ageing time, (b) ageing temperature

3.3. Effect of transfer time on mechanical properties
After solution heat treatment, the heated blank needs to be quickly transferred into the press. This transfer time should be less than the maximum quench delay. Fig. 4 shows the effect of the transfer time on the age hardening. When the transfer time is longer than 10 s, the yield strength and tensile strength decrease. Therefore, the maximum transfer time is 10 s.
3.4. Effect of storage time after solution heat treatment on mechanical properties
In order to gain the strong age hardening, ageing should be performed immediately after solution heat treatment. However, in the real vehicles manufacturing chain the formed parts are common stored at RT for several week before the next heat treatment. The natural ageing happens, and will weaken the subsequent artificial age hardening. Fig. 5 shows the variation of Vickers hardness with the storage time after solution heat treatment. Vickers hardness increases sharply in the first two days, and then stabilizes after 7 days. It means that the natural ageing is strong at the initial stage of storage at RT. For the sample stored at -18 °C in the freezer, its hardness shows the same trend, but the increment is smaller. The low temperature could suppress the natural ageing.

4. Summary
In order to study the effect of the thermal process parameters on the mechanical properties of the final part formed via the hot stamping, AA 6061-T6 alloy samples were heat-treated under different conditions, and then measured by the uniaxial tension and Vickers hardness test. The result shows that
the maximum mechanical properties would be achieved via the solution heat treatment at 560 °C for 40 minutes followed by the ageing at 180 °C for 6 hours. The maximum transfer time of the heated blank into the press to ensure the strong age hardening is 10 s. The low temperature could suppress the natural ageing of alloy.

Acknowledgments
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