Experimental study on the mechanical properties of 7xxx aluminium alloy sheet under different heat treatment conditions

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Abstract. Automotive bodies with high strength aluminium alloys have drawn increasing attentions due to their higher strength and lightweight capability. As one of high strength series of aluminum alloys, peak aged 7xxx series aluminum alloys exhibit superior strength of ~ 600MPa to the conventional lower or moderate strength alloys. However, in spite of the high strength, the lower ductility has been a technical hurdle to be overcome for the material to be applied to press parts at room temperature, which leads to the development of forming technologies at elevated temperature, or namely hot forming. As an alternative to the hot forming, forming trial at room temperature has been made by performing prior solution heat treatment and quenching. This coupled heat treatment and cold forming increases the formability, while the strength needs to be recovered by additional post treatment. The treatment after forming (or deformation) includes natural aging and paint baking process inducing the artificial aging. The objective of the present study is to experimentally investigate the mechanical properties after different heat treatment conditions, which will be utilized for the future finite element simulations for the investigated forming technology.

Keywords: Aluminum alloys, strength recovery, heat treatment, mechanical properties

1. Introduction

The recent requirements for weight reduction in automotive industry have drawn increasing attentions to the lightweight alloy sheets such as aluminum (Al) alloys and magnesium (Mg) alloys. Among these, high strength aluminum alloys such as Al 6xxx or 7xxx series alloys get more attentions owing to their superior strengths to other mild strength level of Al alloys or Mg alloys. However, even with this higher strength, uniform elongation is only around 10%, thus the formability is limited at room temperature, which leads to difficulty for the materials to be applied in the conventional cold forming process. To overcome this inferior formability, the warm or hot forming technology have been often used[1-3]. Forming at high temperature has advantage for its enhanced formability, but it also needs higher cost due to additional facilities for heating and cooling of sheets. Also, tool wear and inferior surface finish after forming are another technical issues to be overcome. In contrast, the cold forming has merits in terms of cost, forming cycle time, and good quality of the sheet surface after forming. The challenge of the cold forming of high strength Al alloys is the inferior formability at room temperature. In this study, as an alternative to the hot forming, a coupled prior heat treatment and cold forming technology is concerned, and the mechanical properties of high strength 7xxx series Al alloys...
before and after heat treatment are experimentally investigated. The heat treatment consists of the solution heat treatment and subsequent quenching before applying mechanical test, which is followed by the post-heat treatment similar to bake hardening process. The final mechanical properties after recovery of strength are discussed as well.

2. Objective
There are several previous works for studying the feasibility of cold forming after prior heat treatment and the recovery of mechanical properties after bake hardening process. This process has been often named as “W-temper” forming [4-6] and its schematic view is shown in Figure 1. According to the previous study, the W-tempered Al 7xxx series (AA7xxx-WT) has lower strength and enlarged elongation than the T6 conditioned one (AA7xxx-T6), which is shown as engineering stress-strain curves for the two conditions in Figure 2. Also, the formed AA7xxx-WT sheet recovered the strength through several aging processes and paint baking process.

Since one of major reasons for utilizing the Al7xxx series for the automotive parts is due to its higher strength, the issue is the recovery of the strength after the final heat treatment process compared to its original T6 condition. The strength change is known to be dependent on the time and temperature during the heat treatment. Therefore, in this study, the strength of each process step is investigated to understand the mechanical properties of the heat treated Al 7xxx alloys. The mechanical properties of each step will be practically utilized in the process design stage using finite element simulations.

3. Experiments
The investigated experimental procedures in this study consist of water quenching after solution heat treatment (SHT), holding between quenching and forming, natural aging and paint baking (PB) process. The overall procedure is schematically shown in Figure 3. After solution heat treatment and water quenching, conventional forming is conducted at room temperature (contrary to the forming at elevated temperature in the hot forming process, which is the most frequently used forming technology for the high strength Al alloys). Then, the formed parts will move to the aging step in which the strength will be partially recovered through the natural aging. Finally, the strength will be fully recovered in the paint baking process if the process parameters are properly controlled.
3.1. Effect of quenching

Previous studies reported that the mechanical properties of the 7xxx series Al alloys are sensitive to the cooling rate after the solution heat treatment [7-9]. To check the sensitivity of the mechanical properties after the quenching, two different cooling methods were selected; water quenching and air quenching. The water quenching has the fastest cooling speed, thus it firmly freezes the solutionized heat-treated matrix. In Figure 4, the engineering stress-strain curves of the Al7xxx alloy sheets under two different cooling conditions are presented for example. As shown in the figure 4, the strength of the water quenched material exhibits much higher strength and even the elongation before fracture is higher than those of air cooled material. The yield strength of the air cooled material is also lower than that of the water quenched sheet. Interestingly, the hardening pattern is also different. That is, the water cooled sheet shows gradually increasing hardening, while the air cooled sheet showed early fast hardening and saturation after about 10% strain. This might be due to the different microstructures after two different cooling methods, which will be further investigated using microstructure analyses.

3.2. Effect of holding time

![Figure 3. The schematic view about whole process of AA7xxx-WT.](image)

![Figure 4. Engineering stress-strain curves of water and air cooled Al7xxx sheets after solution heat treatment](image)
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After the solution heat treatment followed by cooling (water cooling in this study), the holding time is inevitably allowed before the forming process. To study the effect of this holding time before forming, the mechanical properties of the cooled sheets with different holding times were measured. Figure 5 shows the engineering stress-engineering strain curves for four different time, 10, 30, 90 mins and 4 hrs. The figure shows that the strength increases as the holding time increases, but the strengths of the samples with holding times less than 4 hours are very similar. The difference in mechanical properties with holding time is also attributed to the microstructure during the holding time after cooling. For example, the fine size precipitations, called G.P.zone, are generated right after quenching. This G.P. zone is continuously generated during the holding time, which influences the following mechanical properties by controlling the precipitate kinetics.

3.3. Effect of natural aging
After forming at room temperature, the sheets are transferred to the natural aging step, which involves time dependent kinetic process. During the natural aging, the G.P.zone can be also produced at room temperature. As shown in Figure 6, the kinetics of precipitations during the natural aging process changes the mechanical properties significantly. In general, the strength increases as the time for natural aging increases, which has been well known, and the strain hardening patterns are also different depending on the natural aging condition. The strength did not continuously increased, while it saturated after some period. Also, as the natural aging proceeds, the so-called dynamic strain aging phenomenon disappeared, which is also known as the typical properties of the solution heat treated aluminum alloy sheets.

![Figure 5. Engineering stress-strain curve of various holding time](image)
3.4. Effect of paint baking process
The paint baking process is a typical process in the automotive body manufacturing. Therefore, the W-temper forming technology also utilizes this process as final heat treatment process in which the mechanical properties are also recovered. It is well known that the T6 treated Al alloy has reduced strength after the paint baking process. For the comparative study, the mechanical properties of the 7xxx-WT sheets are measured, which is shown in Figure 7. Two different paint baking times are studied; 20 minutes and 80 minutes which are denoted as heat treatment 1 and 2, respectively. The figure shows that the strength of W-tempered sheet increases during the paint baking process but it depends the condition of the paint baking process. Therefore, careful control of the baking process is essential for optimizing the mechanical properties of the W-tempered sheet.

![Figure 6. Engineering stress-strain curves with different natural aging conditions](image)
4. Conclusions
In this study, the mechanical properties of W-tempered 7xxx series high strength aluminum alloy sheets were experimentally measured in each process of the W-temper forming process. The investigated processing factors were cooling method, holding time after cooling, time for natural aging, paint baking condition. Based on the experimental study, the following conclusions are drawn.

- High strength 7xxx series aluminum alloy under W-temper condition showed significant sensitivity on the cooling method after solution heat treatment. The water quenching resulted in reduced strength (400 vs. 600 MPa) and improved elongation (20 vs. 9 %) compared to T6 condition.
- Material properties of the W-tempered sheet is dependent on the holding time (which is between cooling and forming), and they are similar between 10 min to 2 hours.
- Both yield and tensile strengths of W-tempered sheet could be recovered to over 80% of original T6 conditioned sheet by the paint baking process.
- The measured mechanical properties will be useful database for the future numerical simulations for the W-temper forming process.

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