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Experimental quantification of “hardenability” of 2195 and 2050 Al-Li alloys by using cold-rolled sheets

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ABSTRACT

To effectively and intuitively evaluate the “hardenability” during the design of new heat-treatable Al alloys, an experimental evaluation method by using cold-rolled thin sheets was proposed, which combined end-quenching with tensile test after aging, and eliminated the effect of different original structure of thick plate through-thickness. The “hardenability” of 2050 and 2195 Al-Li alloys was then intuitively characterized by their strength lowering as a function of distance away from the quenching end after T8-aging following end-quenching. As the distance is increased, the strength of the 2050 Al-Li alloy lowers more slowly than that of the 2195 Al-Li alloy, indicating a better “hardenability” of the 2050 Al-Li alloy. At the location with a certain distance away from the quenching end, in addition to the Cu-rich secondary phases at the grain boundary, lenticular-shaped Cu-containing secondary phases also form within grains during the end quenching process, which impede the precipitation of T1 (Al_2CuLi) phase at the same local location during the following aging process. More importantly, the number of the intra-granular lenticular-shaped phases in the 2195 Al-Li alloy is much more than that in the 2050 Al-Li alloy, which contributes to a less “hardenability” of the 2195 Al-Li alloy.

1. Introduction

The concept of “hardenability” of a metal alloy is originated from carbon steel. When a steel work-piece is quenched, the surface immediately cools and the Austenite transforms to Martensite or Bainite with a higher hardness. The cooling rate in the inner may be slow enough to allow the Austenite to transform fully into Pearlite, which has a lower hardness. The “hardenability” is an indication of how deep into the steel a certain hardness can be achieved after quenching. However, the “hardenability” of heat-treatable Al alloys is different, because their hardness or strength is enhanced by aging following quenching, but not by direct quenching. The “hardenability” of the heat-treatable Al alloys therefore should be an indication of how deep into the Al alloy a certain hardness or strength can be achieved after aging following quenching. In other words, it refers to the depth where solid solution does not decompose during quenching process. For the heat-treatable Al alloys, it is usually expressed as solid solution stability [1] or quench sensitivity [2,3].

The “hardenability” or quench sensitivity is a critical factor for the heat-treatable Al alloy with large thickness scale. Due to the “hardenability” factor, the strength at the center of thick plates or bulk forgings may be decreased [4,5]. Research on the “hardenability” or quench sensitivity of Al alloys has therefore attracted attention [6–10], and a great deal of research work was focused on 7× × × series Al alloys [11–20]. However, although there exists the “hardenability” factor, the strength at t/2 location of aged 2297 and 2050 Al-Li alloy thick plates was found to be higher than that at the surface, as shown in Fig. 1 [21,22]. This strength distribution through-thickness was associated with texture, re-crystallization degree and stored energy differences, which were dependent on the original structural difference between the surface and the center [21].

According to the Jominy end-quenching test [23], the “hardenability” of the heat treatable Al alloys is characterized through the lowering percentage of the hardness as a function of distance away from the quenching end after a certain aging. However, for the heat treatable Al alloys, the property of strength is of more practical importance than that of hardness. If the “hardenability” of the heat treatable Al alloys is evaluated by strength lowering through-thickness direction, the original structure difference mentioned above absolutely causes an inconvenience to the “hardenability” evaluation. Two following factors therefore should be considered during the “hardenability” evaluation of the heat-treatable Al alloys. (1) It is critical to

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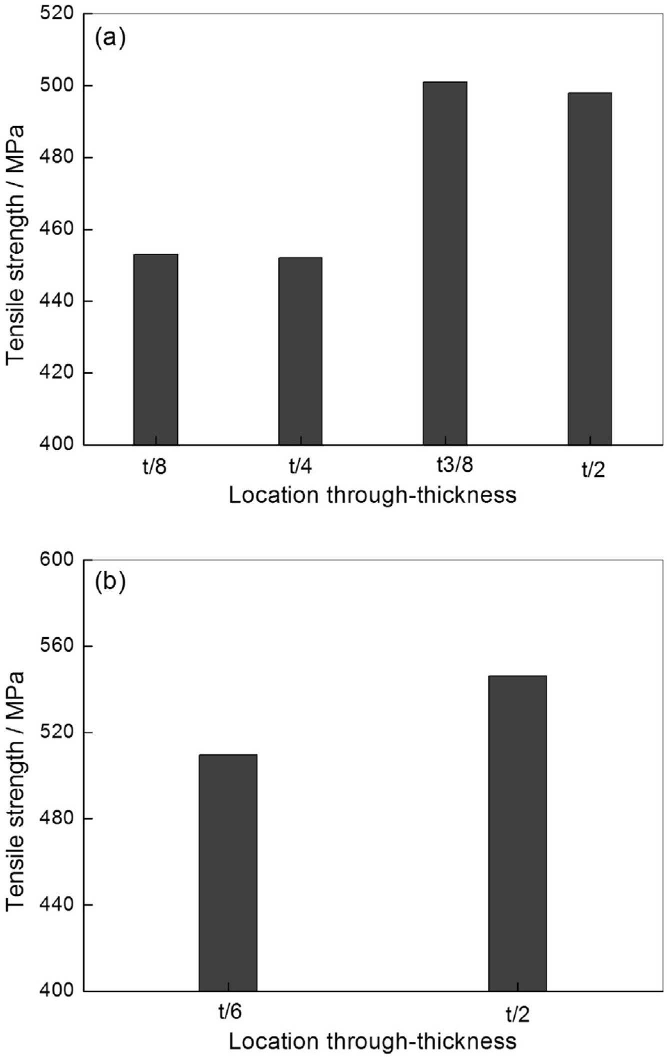

Fig. 1. Tensile strength of T8-aged 2297 and 2050Al-Li alloy plates as a function of location through-thickness. (a) 2297-T87 plate with 85 mm thickness [20]; (b) 2050-T84 plate with 4 in. thickness from NASA report [21].

eliminate the influence of the original structural difference. (2) Strength, but not hardness, is more applicable and more intuitive for the "hardenability" evaluation.

Due to the excellent comprehensive performances, Al-Li alloys attracted intense attention recently in aerospace engineering. According to ASM specifications, Al-Li alloys with different compositions are suited for different section size, due to their different "hardenability". The effect of compositions on the "hardenability" of some Russia Al-Li alloys of the systems of Al-Mg-Li, Al-Cu-Li and Al-Li-Cu-Mg was investigated in the 1990's [24–26].

To design new Al-Li alloys suitable for large section size, their "hardenability" should be evaluated with an appropriate and intuitive method. In addition, the effect of the original structural difference should be eliminated. In this case, a novel experimental evaluation method was designed to investigate the "hardenability" of the heat treatable Al alloys by using cold-rolled sheets, which combined end quenching with tensile test after aging. This method was then applied to compare the "hardenability" of 2195 and 2050 Al-Li alloys.

2. Experimental

Table 1
Chemical compositions of the Al-Cu-Li alloys (mass fraction, %).

Alloy	Cu	Li	Mg	Ag	Mn	Zr	Al
2050	3.60	0.96	0.4	0.4	0.35	0.1	Bal.
2195	3.93	0.97	0.4	0.4	–	0.12	Bal.

The compositions of the 2050 and 2195 Al-Li alloy sheets used in this case are shown in Table 1. The alloy sheets were prepared by cold rolling to a thickness of 2 mm. The sheets were assembled together and solution treated in a salt bath, then experienced end-quenching test, as shown in Fig. 2. After the end quenching, the sheets were disassembled from the assembles and experienced aging, and every sheet was subjected to an artificial T8-aging at 155 °C for 32 h followed by 5 pre-deformation through cold rolling. Tensile specimens with a parallel section gauged 15 mm in length and 3 mm in width were cut at the locations with different distance away from the quenching end in the different sheets along the rolling direction (Fig. 3). The different tensile

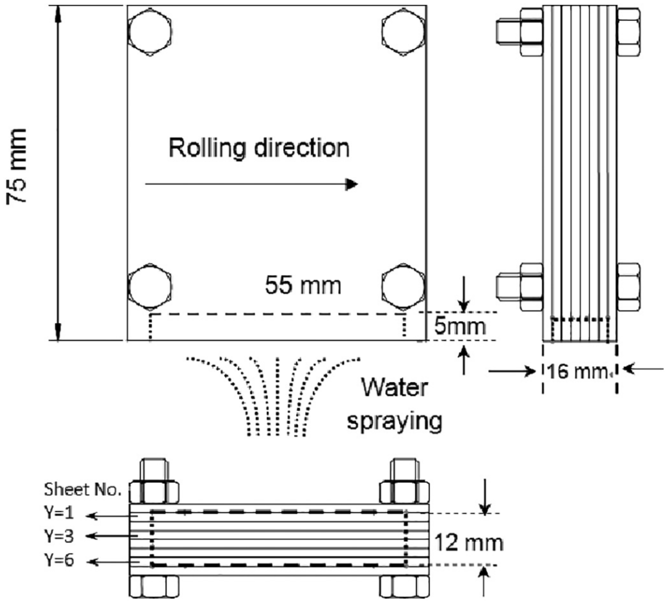

Fig. 2. Diagrammatic sketch for the experimental simulation method for 'hardenability' evaluation by using cold-rolled thin sheets.

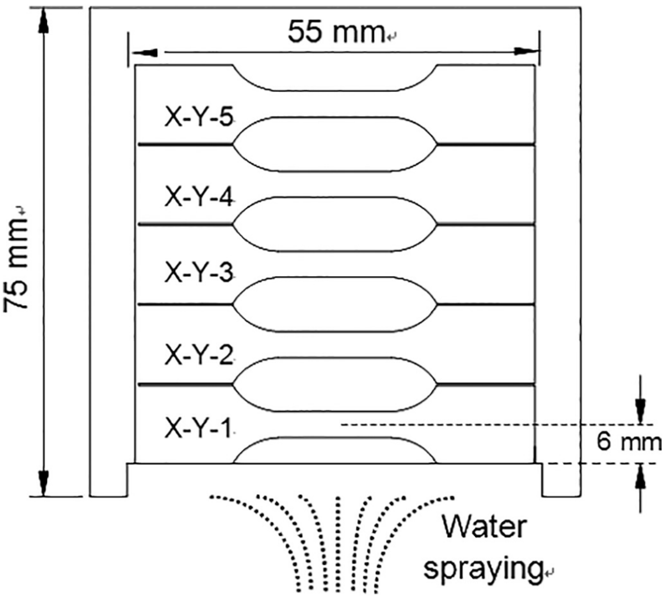

Fig. 3. Tensile specimens cut form the sheets with T8-aging following end quenching.