

Effect of Cooling Method on the Microstructure and Properties of 7085 Aluminum Alloy during Non-isothermal Aging

L. Zhen^{1*}, M. Huang², M. Liu², W. Z. Shao¹ and J. T. Jiang¹

¹ School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China

² Beijing Institute of Aeronautical Materials, Beijing 100095, China

Variation of microstructure and performance of non-isothermal aged (NIAed) 7085 aluminum alloy during slow cooling was investigated. When slowly cooled from 185 °C or 190 °C at cooling rate of 5 °C/h, the conductivity of 7085 aluminum rose quickly and then slowly as temperature decreased, meanwhile, the hardness decreased firstly and then increase. To compare with the air cooling method, slow cooling was observed to bring on higher conductivity at pre-selected strength levels, which may due to the suppression of precipitation coarsening as well as the occurrence of secondary precipitation. The typical performance of 7085 aluminum alloy aged through a non-isothermal process followed by a slow cooling step was found to be higher than that obtained through T74 treatment, which was favorable for performance optimization of large forgings applied in aircrafts. TEM observation revealed that the microstructure of 7085 aluminum alloy treated through NIA process with slow-cooling step was similar to that obtained through RRA treatment. Specifically, the suppression of precipitation coarsening related to the slow cooling was clearly observed, the secondary precipitation however could not be distinct.

Keywords: 7085 aluminum alloy, non-isothermal treatment, slow cooling, mechanical performance, SCC resistance

1. Introduction

7085 aluminum alloy has been widely used in large forgings for its high through-quench, high mechanical performance and high SCC resistance [1]. However, microstructure tailoring and performance controlling of this alloy during post-forging heat-treatment is rather difficult for the complicate thermal condition related to the continuous heating or cooling. Specifically, microstructure evolution together with performance variation resulted from slow-cooling remains unclear. As a slow-cooling step is usually inevitable during hot rolling, homogenization and welding, thus to investigate the materials behavior during this stage is important for performance control of large aircraft components. On the other hand, as FSW has been widely used in manufacturing aluminum alloy components of larger size in aircraft industry [2, 3], the non-isothermal environment resulted from joints cooling can not be avoid completely, post-FSW microstructure evolution during cooling can also be complicated. In fact, currently available results about non-isothermal process have been obtained in studies on FSW process. The effect of slow cooling was previously investigated aiming to develop non-isothermal aging (NIA) technology, the results however are quite limited and most of the results were derived from calculation [4-7]. Thus, a systemic experimental investigation has become imperative to gain deeper insight of the behavior during slow-cooling stage.

The current study then was inspired to investigate the performance evolution of 7085 aluminum alloy during slow-cooling. Hardness measurement and conductivity measurement was performed respectively to evaluate the mechanical performance and SCC resistance.

2. Experimental

Forged-tempered thick plate of 7085 aluminum alloy was used as raw materials in the current study

and the chemical composition of the alloy was shown in Table 1. The specimen for hardness measurement and tensile measurement were cut from the raw plate, solid soluted at 470 °C for 2 h and water quenched to room temperature before aging. Afterwards, these specimens were non-isothermal aged at processes, heating rate (R_h) of 5 and 20 °C/h and stating temperature (T_s) of 100 °C was applied respectively. The specimens were then cooled quickly in air or cooled slowly in oven at cooling rate (R_c) of 5 °C/h. Then Brinell hardness measurement was performed with load of 7350 N and load holding time of 30 seconds. Tensile test of a few specimens were performed on an Instron testing machine at room temperature. Conductivity measurement was applied to indirectly describe the evaluation of SSC resistance, with reference to the previous work [8, 9]. Microstructure of specimen of typical states was observed on TEM (Philips, Tecnai 20).

Table 1 Chemical composition of 7085aluminum alloy (wt.%)

Element	Zn	Mg	Cu	Zr	Fe	Si	Ti-B	Al
Content	7.67	1.69	1.75	0.12	0.026	0.013	0.0022	Balance

3. Results and discussion

Variation of hardness and conductivity of 7085 aluminum alloy during slow cooling was shown in Fig.1. Hardness was observed decreased first at the temperature range of 190~160 °C, then increased gradually as temperature decreased. Contrastively, conductivity was observed increased throughout the cooling stage, first quickly and then become more and more slowly. The decrease of hardness was attributed to coarsening of precipitated phase, which also contributed to the increase of conductivity. This coarsening slowed down as temperature decreased and eventually stopped when temperature was below than 160 °C, the quick increase of conductivity was thus suppressed. The simultaneous increase of conductivity and hardness occurred in satge of 160~100 °C was believed attributed to secondary precipitation. As temperature decreased further to below 160 °C, undercooling of alloy increased and the matrix was converted back to super-saturated state again, the secondary precipitation thus occurred, which then led to a increase of conductivity and hardness. It thus can be found that, slow-cooling treatment led to a more sufficient separation and thus enhanced the strengthening, which then effectively overcome the shortcoming of isothermal or the persistent-heating aging. Additionally, it can be observed that, although variation of hardness and conductivity was similar to each other when cooled from 185 °C and 190 °C, the performance variation at initial stage (when temperature was higher than 160 °C) was much more apparent when cooled from 190 °C. This difference originated from the disparity of heating history. Specimens in case of 190 °C were heated to higher temperature and heat preserved for longer time, precipitation as well as coarsening then occurred more thoroughly than that in case of 185 °C, the hardness then

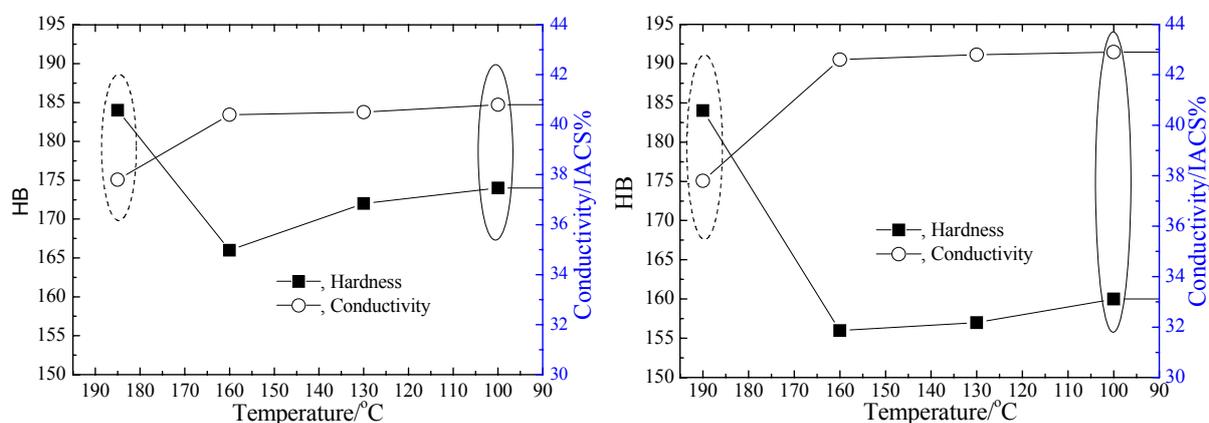


Fig.1 Variation of hardness and conductivity of 7085 aluminum alloy during slow cooling, $T_s=100$ °C, $R_h=20$ °C/h, $R_c=5$ °C/h, (a) cooled from 185 °C and (b) cooled from 190 °C

decreased more quickly when cooled to 160 °C. And that, because of lower super-saturation in case of 190 °C, the secondary precipitation could be much weaker and the increase of hardness was correspondingly suppressed.

Tensile measurement was performed on 7085 aluminum alloy of various states to evaluate the effect of slow cooling. As show in Fig.2, to compare with NIA- air cooled 7085 alloy, NIA-slow cooled alloy possessed higher strength, elongation and higher yield/tensile ratio. Slow cooling treated was observed to optimize the mechanical properties of 7085 aluminum alloy during NIA treatment.

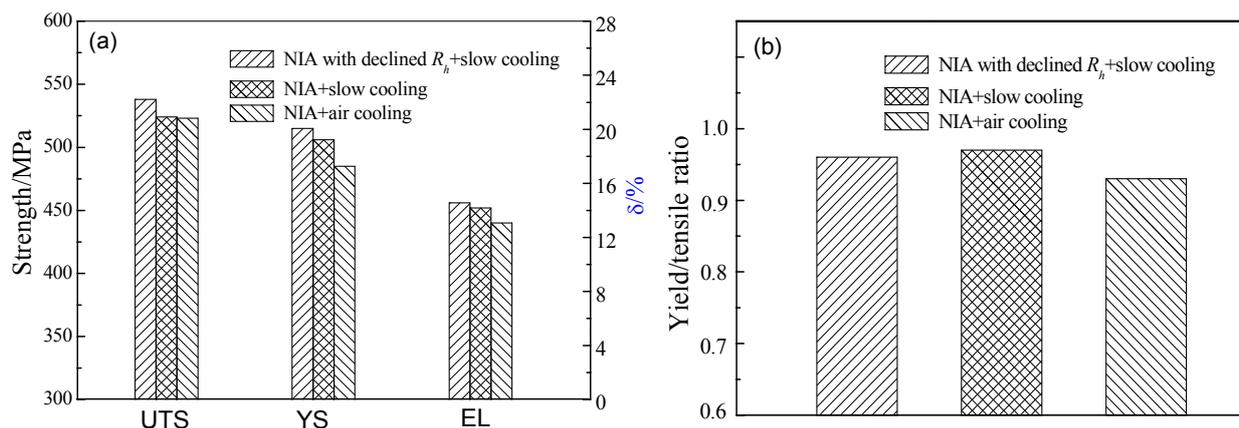


Fig.2 Mechanical performance of 7085 aluminum alloy aged at different process
(a) strength and elongation, (b) yield/tensile ratio

Conductivity of over-aged 7085 aluminum alloy aged at various process was shown in Fig.3. From the figure it could be found that, slow-cooling improved the conductivity apparently and NIA process with slow cooling treatment was found to provide higher conductivity than that of T74 treatment. Specifically, the conductivity of 40.8 %IACS indirectly suggested an excellent SCC resistance according to previous studies [10-12]. Sufficient precipitation driven by secondary separation and the resulted low concentration of element in matrix was believed to be critical for the conductivity improvement.

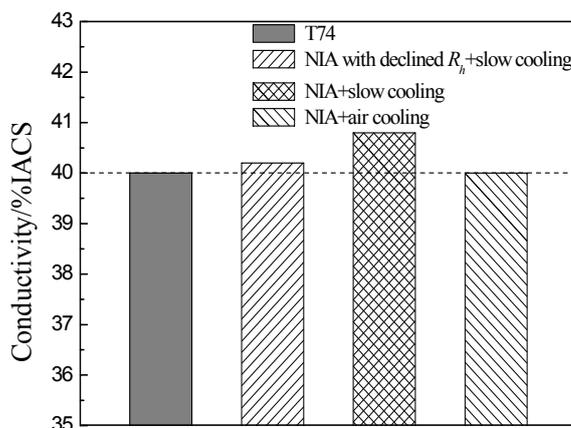


Fig.3 Conductivity of 7085 aluminum alloy aged through different process

Typical TEM image together with the corresponding SAED pattern of 7085 aluminum alloy was shown in Fig. 4. Fine spherical η 's with diameter of 10 nm was observed in grains and coarsened η was observed on the GBs, PFZ with width of 40 nm was clearly observed, which was similar to that

observed at RRA state. SEAD pattern in (b) indicated the presence of η' and η , no patterns corresponding to G.P. zone was observed. Contrastively, finer and needlelike precipitations can be observed in peak-aged alloy, indicating an insufficient separation. When over-aged in an NIA process without slowing cooling, the precipitation coarsened thoroughly, which was quite different from that observed in 7085 aluminum alloy over-aged through NIA process with a slow cooling step, as shown in (a). Comparative observation indicated that, the deleterious precipitation coarsening that occurred in isothermal or persistent heating treatment was effectively suppressed when slow-cooling step was properly controlled. However, presence of secondary precipitations discussed above was not clearly conformed through TEM observation.

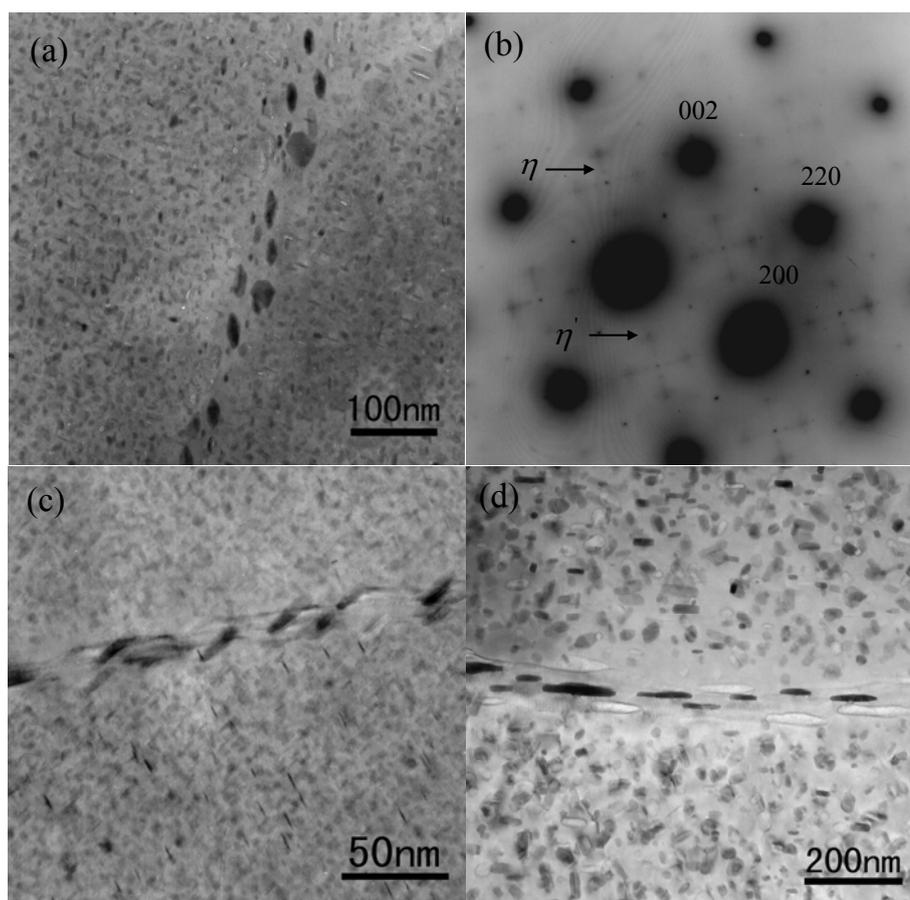


Fig. 4 TEM morphology and the corresponding SAED pattern of 7085 aluminum alloy age through different process, (a), (b) over-aged through NIA process with slow cooling step, (c) peak-aged and (d) over-aged through NIA process without slow cooling

4. Conclusions

The effect of slow cooling on microstructure and performance was studied aiming to get insight of materials behavior during slow cooling stage in post-forge heat-treatment. It was found that, slow cooling could suppress coarsening of precipitation and drive secondary separation, from which microstructure similar to that obtained through RRA process was formed. This control of microstructure led to superior performance including higher strength, high elongation, higher conductivity, and so on, which then supported the high mechanical performance and SSC resistance of forged components. Specifically, yield strength of 504 MPa, tensile strength of 524 MPa,

elongation of 14.1%, yield/tensile ratio of 0.96 and conductivity of 41%IACS was obtained, which was similar than that of T74 state.

Summarily, properly controlled slow-cooling was beneficial rather than harmful for obtaining high performance, which was not only compatible with the forging process but also be helpful for performance optimization. In fact, NIA process with slow cooling was some what similar to RRA process, since a low-high-low temperature combination was introduced to control the microstructure evolution. Additionally, the current NIA process might further overcome the thickness limitation of specimen as in RRA process since it allowed slow heating and cooling. However, the precise microstructure characterization was not achieved in the current study, especially the presence of secondary precipitation that predicted based on age hardening curve was not verified clearly. Thus, further study on microstructure evolution should be performed to promote the study of NIA process and this further work is now under way.

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