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Investigation of Non-isothermal Aging process of 7085 Aluminum Alloy

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Non-isothermal aging (NIA) process of 7085 aluminum alloy was investigated in the current study aiming to obtained good performance combinations through hardness measurement, conductivity measurement and microstructure characterization. The hardness of peak-aged 7085 alloy was observed to slightly affected by the starting temperature as well as the heating rate, which then suggested a wide process scope of non-isothermal aging. The non-isothermal aged 7085 alloy presents high strength as well as high SCC resistance. Specifically, a tensile strength of 524 MPa, an yield strength of 506 MPa, an elongation of 14.2% and an electriccal conductivity of 40%IACS were obtained in NIAed 7085 aluminum alloy of over-aged state, which was near to that obtained through T74 treatment. Additionally, very weak anisotropy was observed in mechanical performances of forged thick plate, which was beneficial for manufacturing huge and muti-way bearing components. TEM observation suggested that the over-aged microstructure of NIAed 7085 alloy was similar to that observed in 7085-T74 specimen.

Keywords: *Aluminum alloy, non-isothermal aging, mechanical performance, SCC resistance*

1. Introduction

To displace builtup structures with large forgings is an effective way to promote the integral manufacture in the field of airspace [1]. Besides forge process, the post-forming heat-treatment is also a crucial step for obtaining high performance, especially for aging hardenable aluminum alloys. The large size of forgings however hinders the performing of usual isothermal aging process, because to heat or to cool large forgings quickly and uniformly is rather difficult. Non-isothermal aging (NIA) processes thus become imperative for this series of applications since the microstructure tailoring is crucial for performance control [2].

Previous study suggested that aluminum alloy of 7000 series should be applied at over-aged state, such as T74, T76 ,T77 and RRA state, to obtain high SCC resistance and high toughness at cost of strength [3]. Among these processes, RRA compromises properly between strength and other two performances by introducing retrogression step, which was quite effective to enhance GB precipitation and simultaneously suppress the growth of intragranular precipitations. The typical microstructure of aluminum alloy treated through RRA process, including dispersed GB precipitations and fine intragranular precipitations, was thought to beneficial for obtaining high SCC resistance at low cost of strength [4,5]. To avoid the complicated and time-consuming experimental, SCC resistance of aluminum alloys was usually indirectly evaluated through conductivity measurements in many works [6, 7], which was believed to be an effective method.

7085 aluminum alloy is a preferred material for large forgings used in load-carrying components in aircraft for its excellent through-quenching property, high mechanical performance and high SCC resistance [1]. However, experimental study on the non-isothermal aging of 7085 aluminum alloy is now quite limited [8-11] and how to obtain good performances including high toughness, high SCC resistance and high strength remains unclear. The current study was thus inspired to investigate the aging behavior of 7085 aluminum alloy during non-isothermal aging. The attention was focused on the strength and SCC resistance.

2. Experimental

Forged and 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. Specimens 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. Immediately after quenched, these specimens were iso-thermal aged at processes with heating rate (R_h) of 5, 10 and 20 °C/h from starting temperature (T_s) of 20 °C and 120 °C respectively. Brinell hardness was then measured with a load of 7350 N and a load holding time of 30 seconds. Tensile test of some specimens was performed on an Instron testing machine at room temperature. The evaluation of SCC resistance was performed indirectly through conductivity measurements on strip specimens 1×1×40mm in size, with reference to the previous work [8]. Microstructure of a few specimens 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

Dependence of hardness on time in 7085 aluminum alloy during NIA treatment was demonstrated in Fig.1. It was apparent that, hardening behavior observed at various processes was similarly to each other: hardness increased gradually to peak values and then decreased quickly. The quick decrease of hardness observed here was attributed to the accelerated coarsening of precipitations driven by the persistently raised temperature. The temperature of isothermal aging of 7000 series aluminum alloy is usually no higher than 160 °C, the much higher temperature in the later stage of NIA in current processes thus led to much higher coarsening rate and quick softening, similar phenomenon was previously observed in 7000 aluminum alloy [12, 13].

Variation of conductivity of 7085 aluminum alloy during NIA was demonstrated in Fig. 2, from which a slightly accelerative increase of conductivity can be observed in various processes. It was thought the knee position at about 150 °C resulted from the massive precipitation of η' phase. It was also found that, T_s affected the conductivity very slightly at very R_h condition. However, conductivity was found to be lower when higher $R_{h,}$ was applied, which we thought was related to less insufficient precipitation resulted from the shorter process duration.

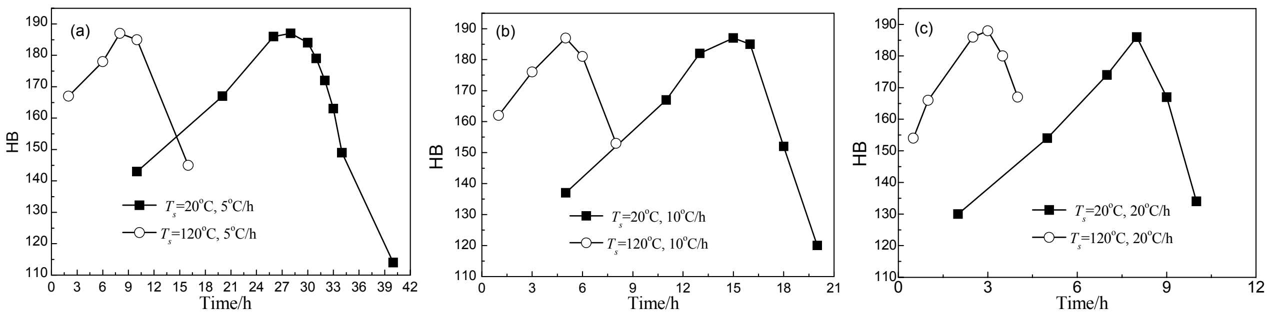

Fig.1 Dependence of Brinell hardness on time in7085 aluminum alloy during NIA with R_h of (a) 5°C/h, (b) 10°C/h and (c) 20°C/h

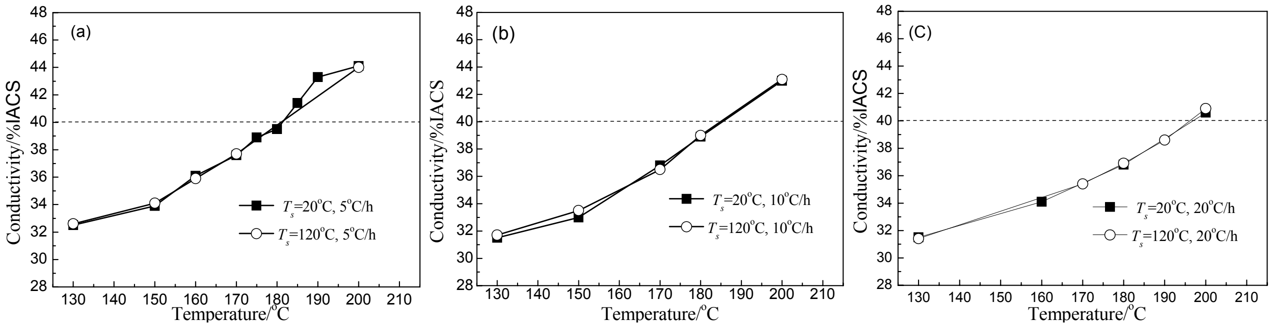

Fig. 2 Dependence of conductivity on temperature of 7085 aluminum alloy during NIA with R_h of (a) 5°C/h, (b) 10°C/h and (c) 20°C/h

The detailed parameters of process as well as performance in cases of peak aged state were derived from curves demonstrated in Fig. 1 and Fig. 2 and listed in Table 2, which can demonstrate more precisely the effect of parameters. Hardness as well as conductivity of peak-aged 7085 aluminum alloy treated through various NIA processes was very similar to each other, which suggested that T_s as well as R_h did not influence the performance significantly in a wide scope. However, the process parameters were found to apparently affect the time and temperature at which a peak-aged state was obtained. As shown in Table 2, temperature increased but time decreased with $R_{h,}$ at cases of either $T_{s,}$ which was due to the effect of temperature on precipitation rate. When higher $R_{h,}$ applied, temperature rise more quickly and precipitation can be accelerated, peak aged state thus can be obtained earlier. On the other hand, increase of T_s from 20 °C to 120 °C was found to greatly shorten the time need to reach peak-aged state with no effect on temperature, indicating that precipitation can hardly occur when 7085 aluminum alloy was heat-treated at temperatures lower than 120 °C.

Table 2 Parameters of peak-aged situation

Process		**Parameters of peak aged state**			
T*s* (°C)	R_h (°C/h)	Time (h)	Temperature (°C)	HB	Conductivity (%IACS)
20	5	28	160	187	36.1
	10	15	170	187	36.8
	20	8	180	186	36.8
120	5	8	160	187	36.0
	10	5	170	187	36.5
	20	3	180	188	36.9

As discussed above, high $R_{h,}$ as well as high T_s was beneficial for aging efficiency with slight effect on performance, thus $R_{h,}$ of 20 °C/h and T_s of 120 °C was applied to heat-treat tensile specimens for verification. The obtained tensile performance in both L and LT direction was shown in Fig.3. The peak-aged state was obtained at temperature of 180 °C, which was consistent to that derived from hardness measurement. Typically, yield strength of 515 MPa, tensile strength of 550 MPa and elongation of 14% can be obtained in 7085 aluminum alloy of peak aged, which was near to that previously obtained at T74 state. Notably, a rather high yield/tensile ratio was observed in 7085 aluminum alloy at peak-aged as well as over-aged state, which was beneficial for exerting the intensity potential of this alloy. It was also found that, the performance measured in two directions were near to each other and the forged plated was nearly isotropic, which is important for large forgings bearing multiway-load, such as the tail girder in aircrafts.

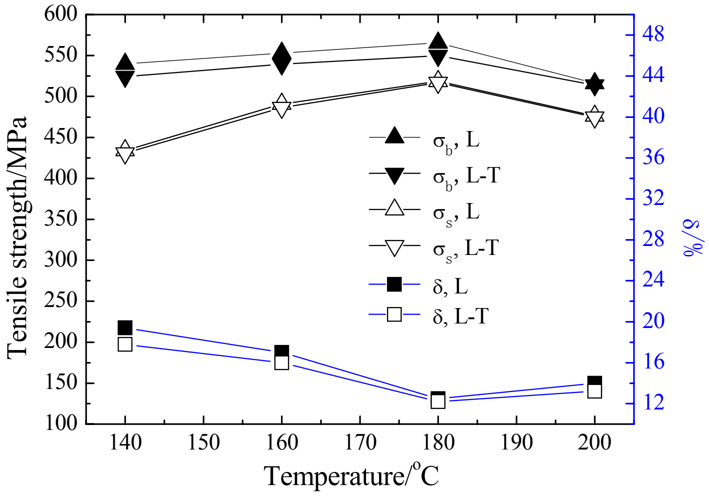

Fig.4 Tensile performance of 7085 aluminum alloy of different state, $R_{h,}=20^{o}$C, $T_s=120\,^{o}$C

However, SCC resistance of peak-aged 7085 aluminum alloy was thought to be low as the corresponding conductivity was lower than 37 %IACS. With reference of previous study on 7000 aluminum alloy, conductivity as high as 40%IACS was believed to be an indication of high SCC resistance [8], which can be obtained at over-aged 7085 aluminum alloy in the current study. Typical performance of over-aged 7085 aluminum alloy treated through NIA process were shown in Table 3, which was similar to that obtained through the typical T74 process.

Table3 Typical performances obtained in non-isothermal aged 7085 aluminum alloy, $R_{h,}= 20^{o}$C, $T_s=120\,^{o}$C

Orientation	Hardness	Temperature (°C)	Conductivity (%IACS)	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)
L	HB165	200	41.2	512	476	14
L-T				510	474	13.2
L	HB173	195	40	529	487	13.6
L-T				523	485	13

The typical morphology of NIAed 7085 aluminum alloy of different state was observed on a TEM and typical images were shown in Fig.5. Very fine precipitations were observed to shape up and diffraction contrast between matrix and precipitation was weak, indicating an under-aged state. When heated to 140 °C. When heated to 180°C, more precipitations with larger size were observed in grains and some coarsened particles appeared on GBs. When heated further to 200 °C, intragranular precipitations coarsened greatly to about 40 nm and the the precipitation on GBs become isolated from each other, which was similar to that observed in specimens of T74 state.

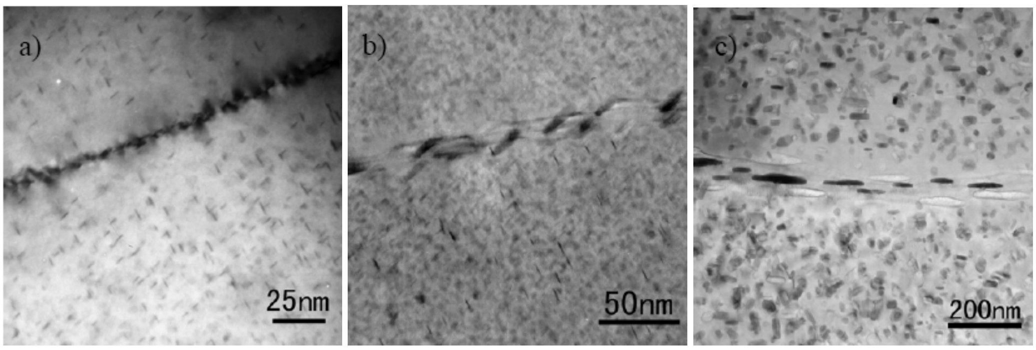

Fig.5 TEM morphology of NIAed 7085 aluminum alloy of different state quenched at (a) 140 °C, (b) 180°C, and (c) 200 °C

4. Conclusions

Non-isothermal aging process was preliminary investigated concerned in the requirement from post-age heat-treatment of large components in aircrafts. Specifically, effect of starting temperature (T_s) and heating-rate ($R_{h,}$) on mechanical performance and SCC resistance was systematically investigated based on measurement of hardness and conductivity. It was found that, T_s, $R_{h,}$ affected hardness and conductivity of peak-aged 7085 aluminum alloy very slightly in a wide range, which then provide a broad process window for post-forge aging. Additionally, high T_s and high R_h contributed to high process efficiency, as observed in the study. Tensile test suggested that, high performance could be obtained through NIA process. Specifically, a tensile strength of 524 MPa, yield strength of 506 MPa, an elongation of 14.2% and an electric conductivity of 40%IACS were obtained, which was similar to that obtained through T74 process. High isotropy of mechanical performances and high yield/tensile ration was observed in the NIAed 7085 aluminum alloy, which was critical for application in components bearing multi-way load in air crafts.

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