

Effect of pre-aging on microstructure and properties of 2000 series aluminum alloy for automotive body sheets

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Abstract: The effect of pre-aging treatment on the tensile properties, formability and microstructures of 2036 aluminum alloy for automobile body sheets were investigated through the tensile tests, DSC analysis and TEM observation. The results show that the alloy was softened, which was pre-aged at 180 °C within 20 min and then natural aging, namely T4P. However, the yield strength decreases first and then rises. The yield strength of the alloy after T4P (10 min) reach the minimal 202.3 MPa, but the elongation and strain hardening exponent arrive at the maximum, 25.5% and 0.26 respectively, which can improve its formability effectively. In the early stage of T4P, GP zones dissolve, and generate some θ'' nuclei, so that the strengthening effect is restrained during the natural aging following the pre-aging. With the increment of pre-aging time, the θ'' phases are formed. The number of the θ'' phases grows, and the strength increases sharply during the paint-bake treatment. In contrast with the 6000 series aluminum alloy for automobile body sheets, the paint-bake hardenability of the 2036 alloy is lower and its yield strength before the paint bake is accordingly higher, which will add the difficulty of forming for the sheet.

Key words: 2036 aluminum alloy; automobile body sheets; pre-aging; property; microstructure; paint-bake hardenability

1 Introduction

With the appearance of global warming and energy crisis, the requirement to improve fuel economy is more and more urgent. To meet the requirement, automotive manufacturers are making efforts to improve conventional engine efficiency, to develop new power trains such as hybrid systems and to reduce vehicle mass. Automotive materials can have an important impact on the environment. The use of lightmass materials can reduce vehicle mass and improve fuel economy. Aluminum, as a kind of lightmass materials, is being applied to the design and exploitation of our vehicles[1–2].

As a material of the automotive body sheets, it is essential to have high strength, formability and corrosion resistance. Meanwhile, it is significant for the material to own the age hardening potential in paint-bake cycles[3–4]. Pre-treatment as a method of heat-treatment, can modify the precipitation characteristic and

performance of alloys[5]. At present, the emphases of most researchers in Japan, Europe and North America are 6000 series aluminum alloys and they found pre-aging of 6000 series aluminum alloys is feasible to improve automotive body sheets[2–3].

However, 2000 series aluminum alloys, which also have a certain age hardening function, are rarely studied as the automotive body sheets. In this work, the authors investigated the effect of pre-aging on the tensile properties, formability and microstructure through different pre-aging treatments of 2000 series aluminum alloys. And it makes great significance for 2000 series aluminum alloys to gain the better strength and formability for the automotive body sheets.

2 Experimental procedures

The Al-Cu sheet used in the present research was a typical 2036 aluminum alloy with 2.5%Cu, 0.5%Mg, 0.5%Si, 0.45%Fe, 0.2%Mn, 0.28%Zn, 0.15%Ti. It was hot-rolled and cold-rolled to thin sheets of 1.2 mm. The

samples were solutionized at 500 °C for 1h, and quenched to room temperature with cooling water[6], and immediately aged at 180 °C for 5–30 min and then naturally aged for 10 d (namely T4P). At last, all the samples were aged at 175 °C for 30 min to simulate the paint-bake cycles.

The tensile properties of the sheet samples were measured before and after the paint-bake treatments to identify the effect of pre-aging treatment on the aluminum alloy. Tensile tests and the measurements of the strain hardening exponent were performed with CSS-44100 model tensile testing machine, on 50 mm gauge length samples taken in the rolling direction with a crosshead speed of 2 mm/min. Differential scanning calorimetry (DSC) tests were performed in the DUPONT9900 model DSC analysis instrument to investigate the precipitation characteristic of the alloys. Microstructural observation was carried out on the H-800 model transmission electron microscope. And the samples were thinned at the MIT-II model twin-jet electropolishing device.

3 Experimental results

3.1 DSC analysis

The DSC curves of the 2036 alloy treated with T4 and T4P for different times (5–30 min) are shown in Fig.1. There are two clear exothermic peaks in the DSC curves, which represent the precipitations of θ'' and θ' phases respectively. With increasing the pre-aging time, the θ'' exothermic peak shifts to lower temperature and gets more flat. And before the exothermic peak, there is an endothermic peak around 160 °C which indicates that GP zones start to dissolve. The DSC curve of the alloy with a 5 min pre-aging treatment at 180 °C is very similar to that of the naturally aged alloy (T4). And there exists a small GP zone peak around 120 °C.

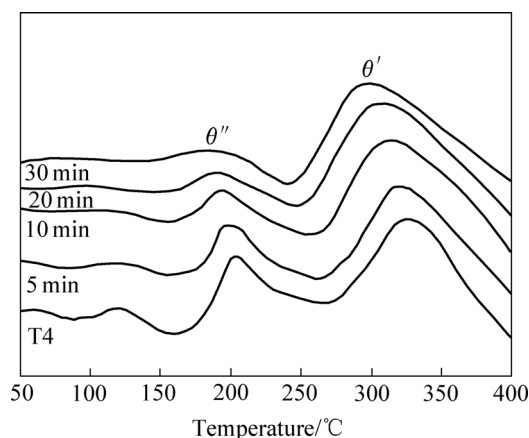


Fig.1 DSC curves of alloy after T4P treatments for different times

Fig.2 shows the DSC curves of the 2036 alloy after T4P (10 min) and then isothermal aging at 175 °C for 30 min. The θ'' exothermic peak of the sample after the paint-bake treatment is obviously lower than that of the sample before the paint-bake treatment. This implies that more θ'' phases are formed in the paint-bake treatment prior to DSC heating.

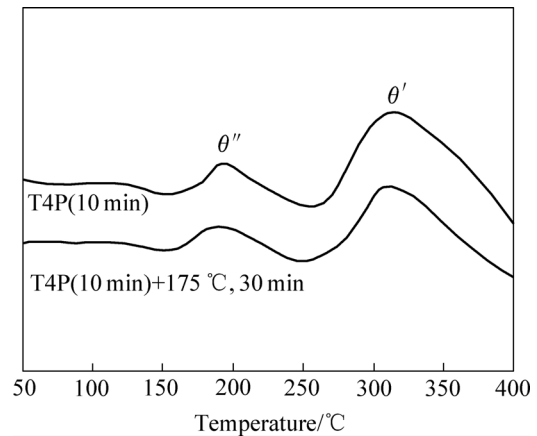


Fig.2 DSC curves of alloy after T4P (10 min) and then isothermal aging at 175 °C for 30 min

3.2 Properties and formability

The results of the 2036 alloy sheet tensile tests performed before and after the paint-bake treatment are shown in Fig.3 and Table 1 respectively, including yield strength ($\sigma_{0.2}$), ultimate strength (σ_b), elongation (δ) and strain hardening exponent (n) along with the paint-bake response (PBR) value, which is the subtraction of the yield strength after and before the paint-bake treatment.

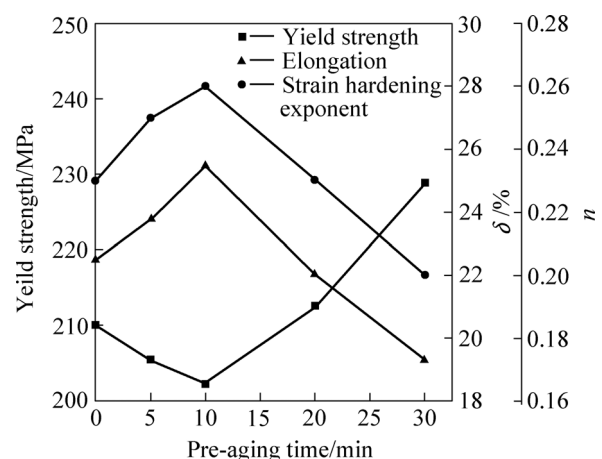


Fig.3 Variation curves of yield strength, elongation (δ) and strain hardening exponent (n) for different pre-aging times

In Fig.3, the point 0 on the horizontal ordinate represents that the sample had no pre-aging before the paint-bake treatment, meaning T4 treatment. It can be clearly seen that the yield strength reduces, but then enhances with the increase of the pre-aging time. And the

change of the elongation and the strain hardening exponent is opposite to that of the yield strength. When the pre-aging time is 10 min at 180 °C, the yield strength of the alloy reduces to the lowest value, 202.3 MPa. The elongation and the strain hardening exponent reach the highest values 25.5% and 0.26, respectively. When the pre-aging time reaches 20 min, its yield strength is above the value of the T4 treatment. After the paint-bake treatment, the yield strength and ultimate strength are improved sharply, but the maximal PBR value is only 60.5 MPa (Table 1).

Table 1 Mechanical properties and formability of alloy after pre-aging treatment

	Pre-aging time (180 °C) <i>t</i> /min	After paint-bake		PBR/ MPa
		$\sigma_{0.2}$ /MPa	σ_b /MPa	
T4	0	250.8	388.7	40.8
	5	254.1	401.3	48.6
T4P	10	257.6	405.1	55.3
	20	272.5	420.6	60.5
	30	278.9	425.2	50.1

3.3 TEM observations

The TEM observations for samples pre-aged at

180 °C for 0 min (T4), 5 min, 20 min with and without the paint-bake treatment are shown in Fig.4. It is seen that θ'' nuclei appear in the matrix after pre-aging at 180 °C for 5 min. And when the sample is pre-aged for 20 min, θ'' phase begins to form, but its number is not very large. In Fig.4(d), it is clearly seen that the density of θ'' phase in the matrix which is pre-aged at 180 °C for 20 min with the paint-bake treatment is much higher than that without the paint-bake treatment. And they are mainly distributed at the grain boundaries.

4 Discussion

4.1 Effect of pre-aging treatment on tensile properties and formability

2036 aluminum alloy belongs to the Al-Cu-Mg series, in which the content of Cu is not very high, only 2.5%, and that of Mg is less than 0.8%. So the main phases are α (Al) and θ phase in 2036 aluminum alloy[7]. The precipitation sequence is typical of the Al-Cu-Mg alloy. It is based on the appearance of the coherent GP zones followed by metastable θ'' phases, then by semi-coherent precipitate θ' phases and by incoherent precipitate θ phases. The GP zones, θ'' phases and θ' phases are the main strengthen particles so the changes of the alloy properties depend on the precipitation of that

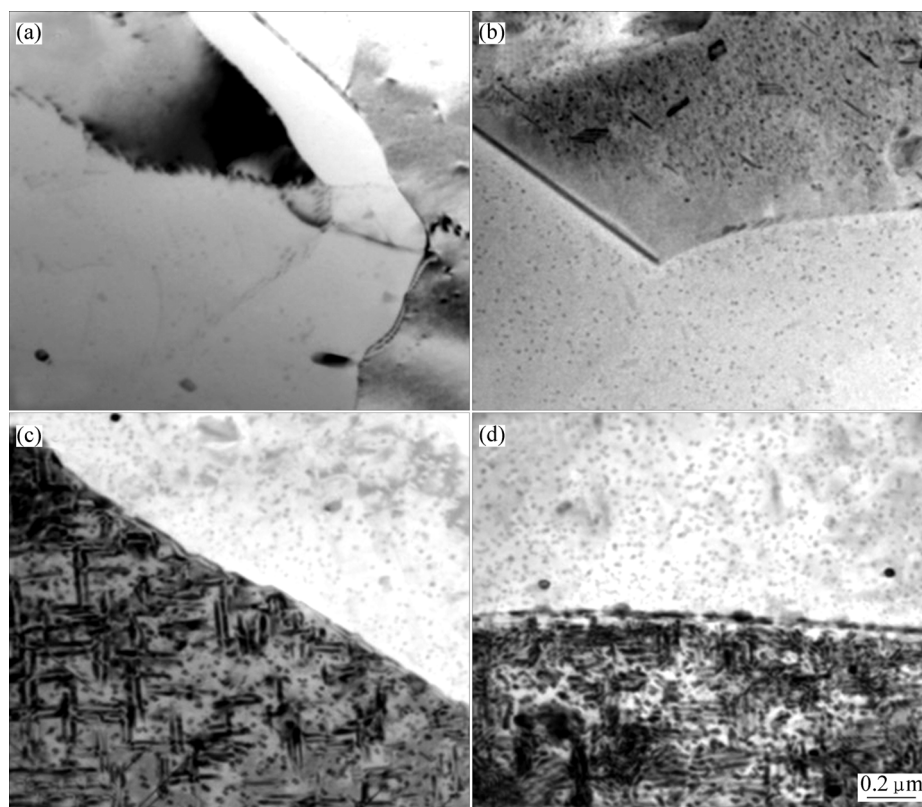


Fig.4 Microstructures of alloy after different tempers: (a) T4; (b) T4P (180 °C, 5 min) temper; (c) T4P(180 °C, 20 min) temper; (d) T4P(180 °C, 20 min) and then aging at 175 °C for 30 min

three particles[8–10].

With increasing pre-aging treatment times, the θ'' exothermic peak shifts to lower temperatures. It is believed that GP zones start to dissolve and become the favorable sites for forming θ'' nuclei during the pre-aging treatment[11–12]. Meanwhile, the dissolution rate of GP zones is faster than the forming rate of θ'' nuclei so the number of GP zones is decreasing slowly. Some θ'' nuclei in the matrix can cause the solute in the supersaturated solid solution to distribute non-homogeneously. So the dislocation density of the alloy rises and the degree of supersaturation decreases in some sites where θ'' nuclei don't exist. It is far easier to form the adsorption of the dislocation organization to quench vacancy so the quench vacancy concentration becomes lower in the matrix. It is reasonable to believe that the formation of GP zones in the alloy is completed through internal diffusion of excess quench vacancy[13–14]. As the pre-aging treatment results in the relative poverty of quench vacancy, the formation of GP zones is suppressed during the subsequent natural aging so that the effect of hardness weakens. This is why the GP zones exothermic peaks have slowly disappeared and in macrography, the strength values of the 2036 alloy decrease and are lower than that of T4, but the elongation and strain hardening exponent are higher. The increasing of the strain hardening exponent means the local anti-necking instability capacity of the 2036 alloy is improving and the deformation is more uniform. So the forming limit of the alloy will be enhanced.

This change in the way the T4P yield strength is affected by pre-aging time. With increasing the pre-aging times, the forming speed of θ'' nuclei accelerates and these θ'' nuclei begin to grow up. When the sizes of these θ'' nuclei reach a certain extent, they are developing into θ'' phases continuously, which leads to the enhancement of the strength.

4.2 Effect of pre-aging treatment on paint-bake response

In Fig.2, the θ'' peak with the paint-bake treatment at 175 °C for 30 min after T4P treatment is flatter than that without the paint-bake treatment and it shifts to lower temperature. This change is associated with the aggregation and growth of the stable θ'' nuclei during the subsequent natural aging. The stable θ'' nuclei are formed with the dissolution of the GP zones. So θ'' phases can be formed more quickly and fully in the subsequent paint-bake treatment (Fig.4(d)). Hence, increasing the population of θ'' phase can provide the enhancement of

the alloy's strength, and generate the bake hardening response.

For studying the bake hardening response quantitatively, a parameter PBR is used in this paper. As for the 2036 alloy, the PBR values are not very large, and the maximal value is only 60.5 MPa (Table 1). Some studies have been carried out on the 6000 series aluminum alloy for automobile body sheets[15]. Their PBR values can reach 110 MPa, and the yield strength before the paint-bake treatment is lower than that of the 2036 aluminum alloy. So using the 2036 aluminum alloy will increase the forming load and difficulty of the automobile body sheets.

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