INFLUENCE OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF RE Al–5.0Mg–0.6Cu ALLOY SHEET FOR AUTOMOBIL BODIES①

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ABSTRACT

The influences of solution temperature, time in solution and quenching rate on the mechanical properties of RE Al–5.0Mg–0.6Cu(wt.–%) alloy sheets for automobile bodies have been studied. The results show the requirements for heat treatments for the alloy sheets were not harsh. Therefore this alloy sheets are easy to produce on an industrial scale. The experiments indicate that there exists slight age hardening in the alloy. The typical microstructures of the alloy have also been analysed.

Key words: heat treatment rare earth Al–Mg–Cu alloy mechanical properties.

1 INTRODUCTION

To lighten the automobile bodies with aluminium alloy instead of steel is one of the most important ways to save energy, reduce pollution and improve a car's overall performances[1]. So far the investigation of aluminium alloys for car bodies has focused on Al–Cu–Mg systems, Al–Mg–Si systems and Al–Mg systems[2–5], of which the Al–Mg systems, because of their corrosion-resistance, ease in welding, excellent workability and formation by stamping, have been widely developed all over the world, especially by Japanese automobile manufactures who are famous for their high efficiency. Recently, great progress has been made in automobile industry in China. In order to improve the competitive strength of China in the world markets, it is urgent to develop aluminium alloys for its own auto mobile bodies. In this paper, the microstructures and mechanical properties of the RE Al–5.0Mg–0.6Cu alloy have been studied with emphasis placed on heat treatment of the alloy.

2 ALLOY PREPARATION AND EXPERIMENTAL METHODS

The composition of the studied alloy is Al–5.0Mg–0.6Cu (wt.–%)[6]. In order to make good use of the rich natural reserves of rare earth metals in China, 0.2wt.–% Ce was added, and trace amounts of rapidly solidified Al–5Ti–1B powder were also added. The alloy was melted in a graphite crucible by an electric furnace. The molten alloy was cast into 5 kg flat ingots, then hot and cold-rolled into sheets of 1 mm thickness for use.

Mechanical properties of the alloy were measured on a WD–10A type universal electric testing machine. The tensile rate was 2 mm / min and the sizes of the samples are shown in Fig. 1. The values of the mechanical properties were the averages of 3 ~ 5 samples.

X–ray diffraction analysis was conducted on a D500 type diffractometer (Cu Kα, 40 kV ,

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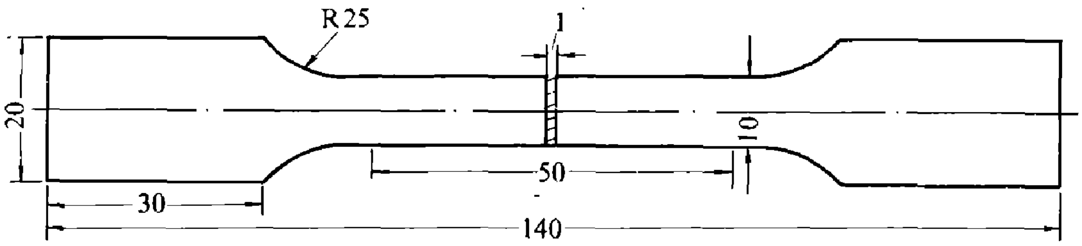

Fig. 1 Sketch of sample for tensile test

2 ℃ / min) with 20 mm × 15 mm × 1 mm samples. The samples were solution heat treated, then mechanically polished and destressed by electrol- ytic polishing. The electrolyte was composed of 9 wt.−%CrO_3, 5.2 vol.−% H_3PO_4, 14 vol.−% H_2SO_4, 20 vol.−% H_2O. the samples for microscopic observation were prepared as above but without electrolytic polishing, and the corrosive agent is $1HCl+2HNO_3+1HF+96H_2O$ (vol.%).

EDA experiments were performed on a X−650 type SEM for microscopic observation samples and the tensile fracture surface respectively.

The samples for TEM observation were mechanically thinned and punched with a mixture of 30 HNO_3+70 CH_3OH (vol.−%) at −30~20 ℃, and then observed with a H−800 TEM at an accelerating voltage of 200 kV.

3 RESULTS AND DISCUSSION

3.1 *Effect of Solution Temperature on Mechanical Properties of* Al−5.0Mg−0.6Cu *alloy*

Fig. 2 shows the mechanical properties curves of the studied alloy, which was solution heat treated at different temperatures for 1h and then water-quenched to room temperature. It can be seen that the values of the strength σ_b, $\sigma_{0.2}$ and the elongation δ increase with increasing solution temperature.

At 470 ℃ , the values of σ_b, $\sigma_{0.2}$ and δ are respectively 280 MPa, 115 MPa and 30%. When the solution temperature exceeds 550 ℃ , there appear overheated structures in the alloy, and the mechanical properties of the alloy become extremely poor. Therefore, the reasonable solution temperature range for the alloy is 470~530 ℃.

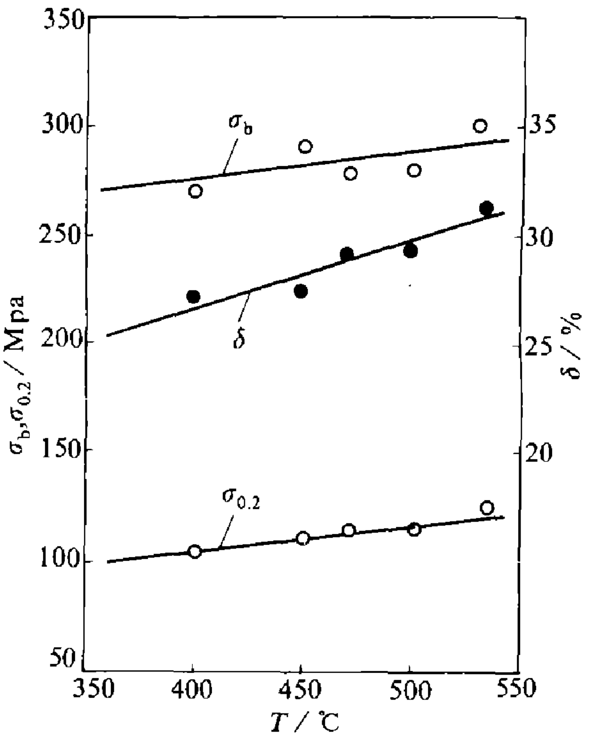

Fig. 2 Mechanical properties of RE Al−5.0 Mg−0.6Cu alloy versus solution temperature

3.2 *Influence of Time in Solution on Mechanical Properties of* Al−5.0Mg−0.6Cu *Alloy*

Fig. 3 shows the mechanical properties curves of the studied alloy, which was solution heat treated at 470 ℃ for different times and then water-quenched to room temperature. It is clear that the mechanical properties of the alloy improve with increasing solution times. After a solution teatment, the values of σ_b, $\sigma_{0.2}$ and δ can reach 290 MPa, 123 MPa and 31.1% respectively. Because their slow change a reasonable solution time can be considered to be 20 min~2 h.

3.3 *Influence of Quenching Rate on the Mechanical Properties of* Al−5.0Mg−0.6Cu *Alloy*

Table 1 lists the data for the mechanical properties of the alloy, which was solution heat treated at 470 ℃ for 20 min and then quenched at different rates. It can be seen that the values of σ_b, $\sigma_{0.2}$ increase with decreasing quenching rate but the value of δ changes little.

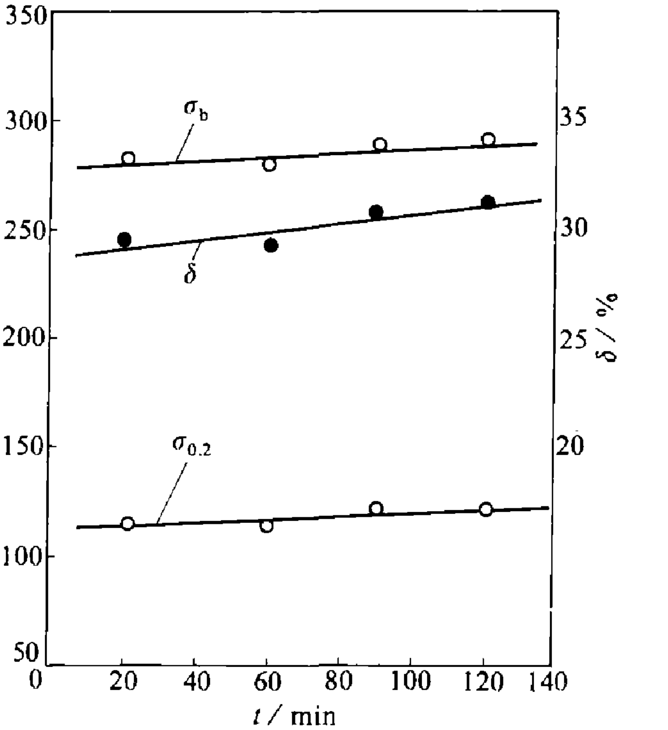

Fig. 3 Mechanical properties of Re−5.0Mg−0.6Cu alloy versus solution time (solution temperature: 470 ℃)

Fig. 4 shows the tensile curves (σ−ε) of the alloy quenched at different rates. There exists a yield platform under the condition of air cooling, and there appear to be similar platforms cases under the conditions of strong breeze cooling and natural cooling on asbestos board. Generally speaking, the existence of this kind of yield platform means the appearance of Lüders bands in the alloy, which affect the surface quality of the alloy later formed by stamping.

But from Fig.4, it can be seen that the strain of the yield platform is only 0.8%. Whether it influences the surface quality of the alloy after formation by stamping needs further investigation. If the influence is very small, then a lower quenching rate may be adopted for the convenience of industrial production.

3.4 *Typical Microstructures of* Al−5.0Mg−0.6Cu *Alloy*

The typical microstrutures of RE Al−5.0Mg−0.6Cu alloy are shown in Fig.5, from which the following facts can be gleaned.

(1) No detrimental needle-like phases such as Fe_3Al appear in as-cast (Fig.5(a)), cold rolled (Fig. 5(b)), annealed (Fig. 5(c)) and solution heat

Table 1 Mechanical properties of RE Al−5.0 Mg−0.6Cu alloy quenched to different rates (T = 470 ℃, t = 20 min)

Cooling conditions	σ_b / MPa	σ_{02} / MPa	δ / %
Water-quenched at RT	288	118	29.5
Strong breeze cooled	300	128	31.2
air-cooled	305	137	29.7
naturally cooled on asbestos board	321	141	30.0

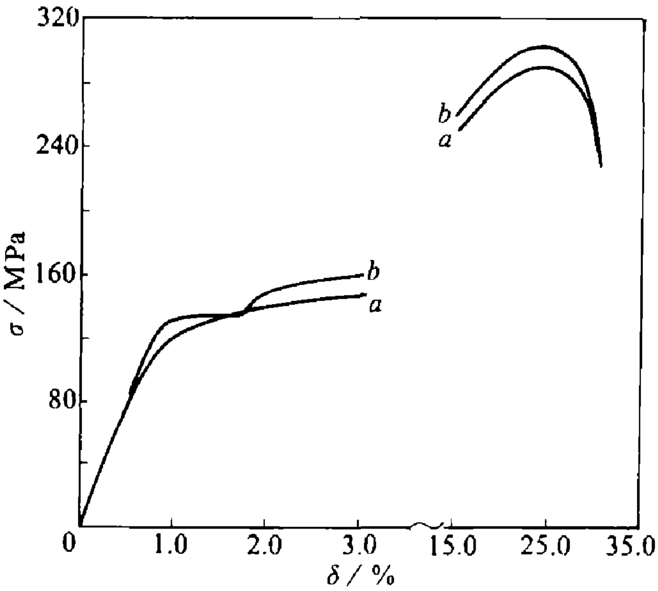

Fig. 4 σ−δ Curves of RE Al−5.0Mg−0.6Cu alloy

a—water-quenched; *b*—air-cooled

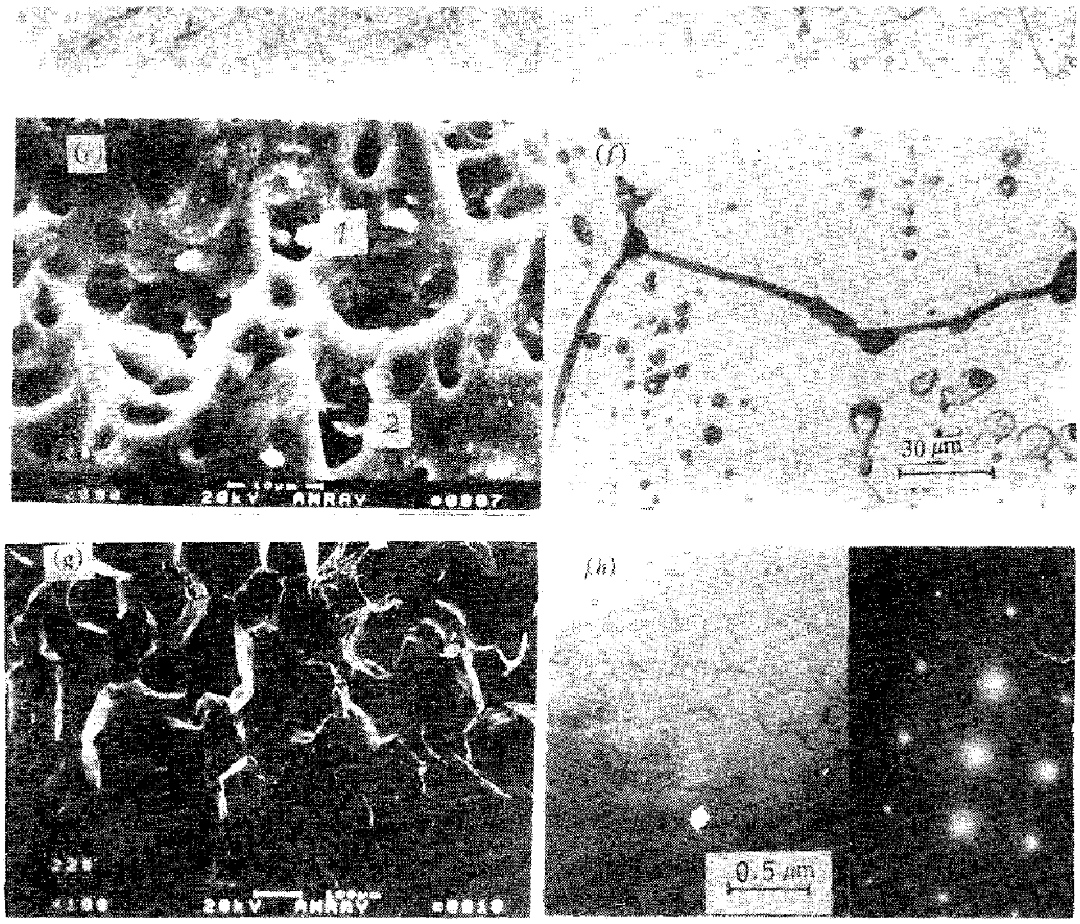

Fig. 5 Typical microstructures of RE Al−5.0Mg−0.6Cu alloy

(a)—as-cast; (b)—cold rolled(polarized light); (c)—annealed; (d)—quenched; (e) fracture morphology of quenched sample(SEM); (f)— overheated (55 ℃, 1h); (g)— fracture morphology of overheated sample(SEM); (h)— TEM micrograph and electron diffraction pattern(001)* for aged sample (175 ℃, 1h) treated (Fig. 5(d)) samples.

(2) The as-quenched microstructure of the alloy is a solid solution composed of α–phase, on which are distributed foreign substances brought in during casting. (Fig.5(d), Fig.6). In the cold roi- led state, the impurities distributed along the rolling direction, and annealing or heat treating in solution didn't change their distribution orientation (Fig. 5(b)–(d)).

(3) After solution treatment, the amount of impurities decreased. This means that part of them (such as Mg_2Al_3, $CuMgAl_2$) could be solutionized.That the mechanical properties of the alloy increase with increasing solution temperature and solution time may be ascribed to the solution degree of the alloy. The lattice constant of the base metal aluminium (4.070A) calculated from the XRD patterns shown in Fig. 6 is larger than that of the pure aluminium (4.049Å). This implies that the alloy is mainly solution hardening.

(4) The tensile fracture surface of the as-quenched alloy appears to be sheared fracture (Fig. 5(c)). This indicates ductile failure of the alloy. From the EDA data in Table 2, we know that the small particles such as points 1 and 2 in the tough combs in Fig. 5(c) are rich in rare earth metals and have high concentrations of Fe, Si, Cu and Mg. This means that rare earth metal can improve the distribution of detrimental elements, such as Fe and Si, to inhibit the formation of needle-like phases, and then improve the mechanical properties of the alloy to some extent.

(5) When overheated, the grains of the alloy grew rapidly. There existed cracks on the grain boundaries after quenching and eutectic structures of low melting points along the grain boundaries (Fig. 5(f)). The overheated fractures (candy-like) are of typical intergranular failure (Fig. 5(g)).

(6) In Table 3, the values of the mechanical properties of the alloy are compared with the quenched state and the aged state (175 ℃, 1 h, simulated paint roasting). It is shown that the strength increases and ductility decreases after ageing.

Therefore, there exists slight age hardening in the alloy. Fig.5(h) shows the TEM micrograph and the corresponding diffraction pattern of the aged alloy. There exists artificial age hardening in the alloy and no new diffraction speckles appear. Therefore, the fine granular precipitates in the TEM micrograph can be preliminarily determined G. P zones and the age hardening mechanism of the alloy is precipitation strengthening.

Table 2 EDA data of RE Al–5.0Mg–0.6Cu alloy

particle 1				particle 2			
element	wt.–%	at.–%	S.E%	element	wt.–%	at.–%	S.E%
Mg	9.19	5.85	3.81	Mg	10.04	12.39	1.16
Al	91.98	93.01	0.65	Al	72.24	80.23	0.27
Ce	1.24	0.24	35.15	Si	1.30	1.39	5.16
Fe	0.68	0.33	25.91	Ce	7.22	1.55	2.52
Cu	1.30	0.56	22.01	Cu	9.20	4.34	1.46

Table 3 Comparison of mechanical properties of RE Al–5.0Mg–0.6Cu alloy with those of the quenched state and aged state(175 ℃, 1 h)

state	σ_b / Mpa	$\sigma_{0.2}$ / MPa	δ / %	HB
quenched	288	118	30.7	66.0
aged(175 ℃, 1h)	330	141	27.9	72.4

4 CONCLUSIONS

(1) The mechanical properties of RE Al–5.0Mg–0.6Cu alloy improve with increasing solution temperature and solution time. This may be ascribed to the degree of solubility of the alloy;

(2) The strength of the alloy increases with decreasing quenching rate and there appears a yield platform when the quenching rate is lower than a certain value;

(3) With regard to the convenience for its production on an industrial scale, the alloy may be heat treated at 470～530 ℃ for 20 min～2 h and then cooled by a strong breeze;

(4) The typical values of mechanical prop-

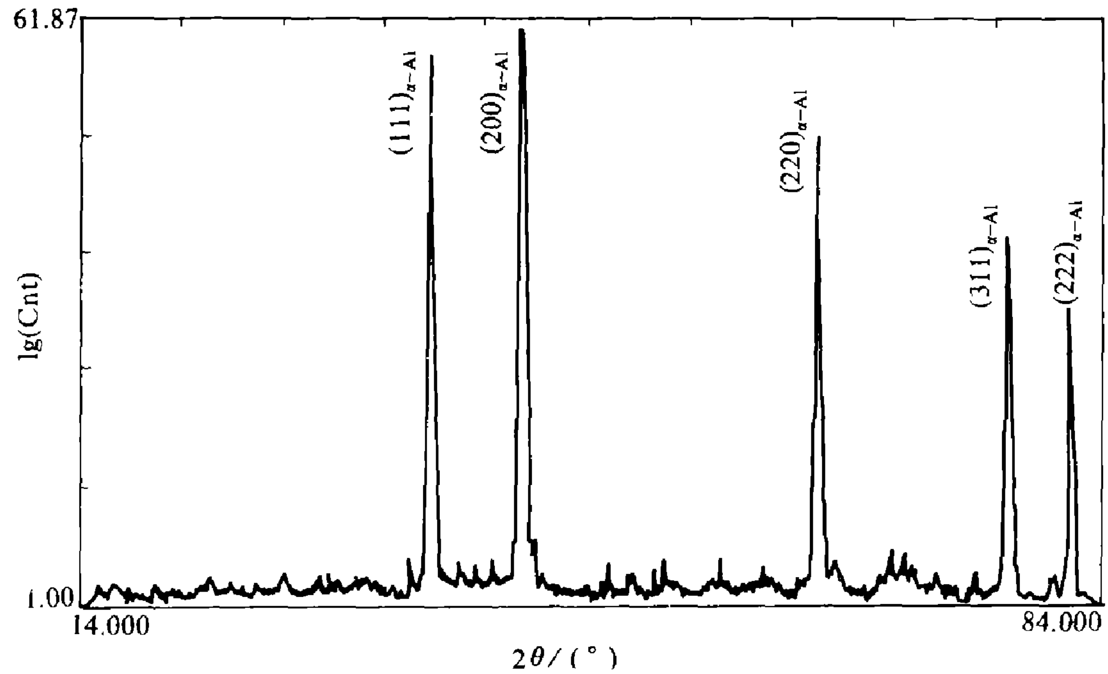

Fig. 6 X—ray diffraction pattern of as-quenched RE Al–5.0Mg–0.6Cu Alloy

erties of the alloy are $\sigma_b=290$ MPa, $\sigma_{0.2}=123$ MPa and $\delta=31.1\%$. And there exists slight age hardening in the alloy. Therefore it is an ideal material to be used as automobile body sheets.

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