EFFECT OF EXTRUSION TEMPERATURE ON PROPERTIES OF Al-Fe-X ALLOY①

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ABSTRACT

Multi-stage RS powder-making device was applied to produce Al-Fe-V-Si alloy powder. The powder filled in rubber cans was consolidated by means of CIP. The effect of preheat temperature on the properties of elevated temperature RS Al-Fe-V-Si alloy was investigated. The microstructure of the samples was observed by TEM. The relationship between hot processing parameters and properties of Al-Fe-X RS alloy was discussed.

Key words: extrusion extrusion temperature precipitate

1 INTRODUCTION

Ever since the middle 1970s, lots of work has been done on elevated temperature Al alloys. Because of their low density and excellent mechanical properties at high and room temperature, elevated temperature Al alloys has drawn great attention from the material scientists and technologists all over the world. They are expected to replace the heat resisting steel and Ti alloys in the field of aerospace[1]. At present, the elevated temperature Al alloys under study can be divided into three types[2]: (1) technically mature alloys with representives of Al-Fe serial alloys and Al-Cr-Zr serial alloys, (2) alloys with a high volume fraction of precipitate such as Al-Cr-Y, Al-Mn-Si, (3) alloys with a low interfacial energy such as Al-Zr-V. Among those alloys, Al-Fe based ternary or quaternary alloys are the most mature alloys whose behaviors have been investigated extensively[3]. During the fabrication of elevated temperature Al alloys, powder-making process, consolidation and forming are the critical steps. In addition, according to the experience from our research work and concerned scientific literatures, forming process (after consolidation) is so complicated that it is difficult to put it under control. It becomes the main factor determining the final properties of the alloys. The reason lies in the fact that on the one hand the processing properties of super-saturated Al alloys produced by means of RS is not satisfactory yet; on the other hand, RS Al alloys still exihibit high deformation resistance at elevated temperature. Furthermore, in order to obtain good mechanical properties, we shall take it into account that at high temperature, the super-saturated alloys will decompose and the precipitates will coarsen. From our point of view, hot process is the main factor preventing further progresses in the research work on elevated temperature Al alloys. Consequently, this article focuses on the relationship between extrusion temperature and properties of Al-Fe-V-Si alloy.

2 EXPERIMENTAL

Al-8.5Fe-1.3V-1.7Si (wt.-%, nominal composition) powder was obtained by multi-stage rapid solidification[4,5]. After having been screened, the powder of interesting size was filled in rubber cans. Then the powder was consolidated

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into billets with a density of ~75% theoretical at room temperature by means of CIP. Furthermore, for billets consolidated by CIP degassing is also needed.

In order to investigate the effect of extrusion temperature (the preheat temperature of the billets) on the properties of the alloys. Six preheat tempertures 400, 420, 450, 480, 500, 520 ℃, were chosen according to the equipment condition respectively. In determining the preheat time, the size of the billets and the thermal conductivity had been taken into account, for an inappropriate preheat time will cause either the ripening of the precipitates or thermal nonequilibrium. The die and the container were also preheated to 300 ℃. Then these billets were extruded to bars on a 500t extruder under different process conditions.

3 RESULTS AND DISCUSSION

Bars obtained by extrusion were made into cylinder tensile specimens (M8). These specimens were tested at room temperature, 350 and 400 ℃ respectively. The experimental data are listed in Table 1.

Table 1 Mechanical properties of extruded specimens

No.	T_E/℃	F_E/t	RT			350 ℃				400 ℃		
			$\sigma_{0.2}$	σ_b	δ	E	$\sigma_{0.2}$	σ_b	δ	$\sigma_{0.2}$	σ_b	δ
			/MPa		%	/GPa	/MPa		%	/MPa		%
I	400	255	437	454	7.6	81	212	236		153	165	
II	420	229	432	455	7.8	78	214	240		158	170	3.5
III	450	217	430	465	8.5	78	210	246	6.9	162	176	6.4
IV	480	210	430	458	9.2	76	218	251	5.7	149	174	5.0
V	500	201	417	460	9.0	75	200	230	4.5	153	166	3.0
VI	520		388	420	6.9	67	176	214	4.0	137	155	4.2

Notes: T_E —extrusion temperature; F_E —extrusion force; RT—room temperature

Table 1 shows that there appears no appreciable change in the properties as the preheat temperature varies between 400 ℃ and 500 ℃. However when it reaches 520 ℃, the properties degrade sharply. In contrast, the extrusion force changes greatly with the change of preheat temperature. Furthermore, the higher the temperature, the lower the extrusion force. This can be explained by the decrease of the deformation resistance due to the rise of the preheat temperature. For example, an extrusion force of 255t which is close to the limitation of our equipment was needed for billets preheated at 400 ℃, but if the preheat temperature rises up to 500 ℃, the force drops to 200t or so. Consequently, a higher preheat temperature is appreciated with regard to the process of the material. However, in order to optimize the properties, it is necessary to lower the temperature. The precipitate ripening rate is given by[6]:

$$\frac{dr}{dt} = D \cdot c \cdot \sigma \cdot r^{-2} \qquad (1)$$

where r is the precipitate size; $\frac{dr}{dt}$ is the interfacial energy between the matrix and the precipitates; c is the equilibrium solubility. According to the above relation, the increase of the diffusion coefficient D and the equilibrium solubility c due to the rise of the temperature will lead to the increase of the precipitate ripening rate and the degradation of the mechanical properties of the alloys. It is generally believed that a lower preheat temperature is necessary for excellent final properties. However, the experimental results show that there exists a proper temperature range, in which the rise of the preheat temperature will not result in the rapid ripening of the precipitates.

From our point of view, the upper limitation of this temperature range is lower than 500 ℃. The experimental data listed in Table 1 show clearly that as the preheat temperature rises from 400 ℃ to 500 ℃, no appreciable change in the elevated temperature properties and room temperature properties takes place. It is mainly due to the temperature rise during process. According to ref. [7], the highest temperature of the billets during extrusion is not only determined by the preheat temperature and the temperature of the die, the heat of friction and the heat of deformation are to be taken into account too. There are three contributions to the temperature rise during the extrusion process[8]. The first ($\triangle T_1$) is due to deformation work. The second ($\triangle T_2$) is caused by the friction between the inner side of the container and the billet. The last ($\triangle T_3$) results from the friction at the die land. They are given by[8]:

$$\triangle T_1 = \frac{K_f \cdot \varphi}{\rho \cdot C_p} \quad (2)$$

$$\triangle T_2 = \frac{K_f}{4\rho \cdot C_p}\sqrt{\frac{V_a \cdot L_0}{d \cdot R}} \quad (3)$$

$$\triangle T_3 = \frac{K_f}{4\rho \cdot C_p}\sqrt{\frac{S \cdot V_a}{d}} \quad (4)$$

where K_f is the deformation resistance; φ is the nature logarithm of extrusion ratio; $\lambda(\varphi = \ln\lambda)$, C_p is the specific heat of the billets; ρ is the density of the material; V_a is the velocity of the metal flow at the exit; L_0 is the billet length; d is the thermal conductivity; S is the length of die land. According to these relations, the critical factor causing the temperature rise is K_f. During extrusion, the smaller the K_f, the smaller the extrusion force and temperature rise. As for the studied alloy, when the preheat temperature of the billets was only 400 ℃, the deformation resistance of the material was large, which leads to a considerable temperature rise. As a result the actual temperature of the products after extrusion was by far higher than 400 ℃. On the contrary, when the billets were preheated up to 500 ℃, the deformation resistance dropped sharply. So the temperature rise $\triangle T$ is rather small and the temperature of the products after extrusion is nearly equal to the preheat temperature. Consequently, to be exact, the final properties of the extruded bars are determined by the temperature of as-extruded samples. In order to demonstrate that there exists a temperature range (400 to 500 ℃) which is appropriate for the extrusion of RS Al-Fe-V-Si alloy further experiment were made.

The typical microstructures of hot extruded samples after heat treatment at 400, 450, 500, 520 ℃ for 10h respectively are shown in Figs. 1(a—d). Before extrusion, these billets had been preheated to 400 ℃. In Figs. 1(a—c), fine precipitates of similar size can be found. However, Fig. 1

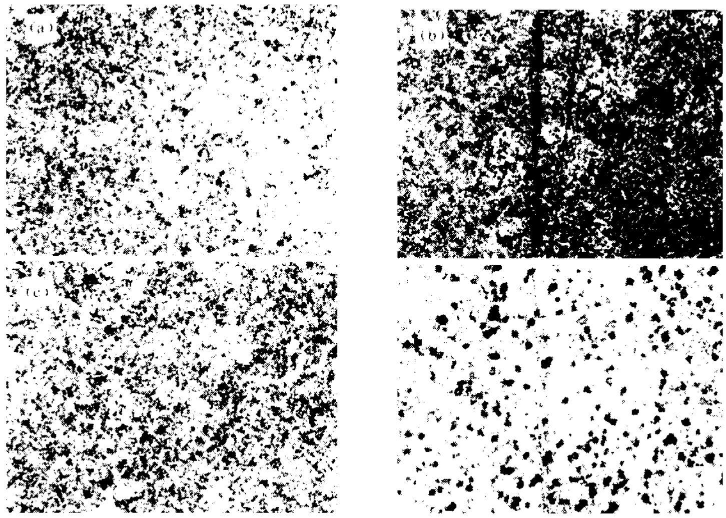

Fig. 1 Microstructures of Al-Fe-V-Si hot extruded bars after heat treatment at different temperature for 10h, ×500

(a) 400 ℃; (b) 450 ℃; (c) 500 ℃; (d) 520 ℃

(d) shows that a part of the precipitates has coarsened already. So a preheat treatment at 520 ℃ will result in poor properties of the hot extruded products.

Fig. 2 shows the dependence of the hardness on ageing temperature. It can be seen that the hardness of the samples is preserved as the temperature rises from 400 ℃ to 500 ℃. However, when the temperature is over 520 ℃, the hardness will decrease sharply.

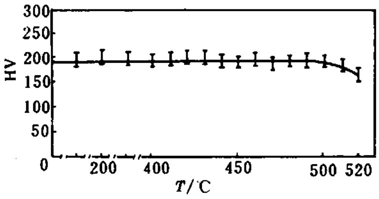

Fig. 2 Change in the hardness *vs* the heat treatment temperature

Figs. 3(a, b) are the TEM micrographs of hot extruded samples preheated at 500 ℃ and 520 ℃. In Fig. 3(a), fine precipitates are observed. However precipitates in Fig. 3(b) are relatively large. Electron diffraction was applied to analyze the samples. The results show that the precipitates in Fig. 3 (a) are $Al_{12}(Fe, V)_3Si$. However, in Fig. 3(b), besides $Al_{12}(Fe, V)_3Si$, the equilibrium phase δ-(Al, Fe, V, Si) is also found.

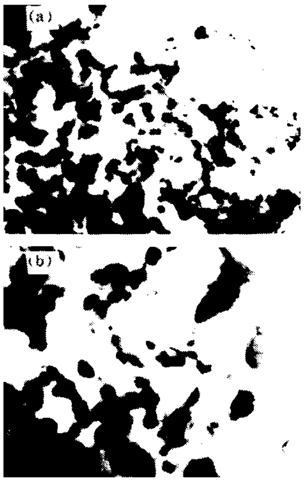

Fig. 3 TEM micrographs of hot extruded bars preheated at different temperatures
(a)—500 ℃; (b)—520 ℃

4 CONCLUSIONS

(1) As to elevated temperature RS Al-Fe-V-Si alloys, a short period of preheat at a temperature lower than 500 ℃ will not lead to rapid coarsening of the precipitates. The billets can be preheated at any temperature between 400~500 ℃.

(2) The key factor determining the properties of the elevated temperature RS Al-Fe-V-Si alloy is the temperature at which the metal flow from the die. Because of the relationship between deformation resistance and temperature rise during the extrusion process, under certain conditions, the preheat temperature will not have any appreciable effect on the final properties of the alloy.

REFERENCES

1 Cheng, Tianyi; Zhang, Shouhua. Rapid Solidification Techniques and New Alloys. Beijing: Aerospace Press, 1990.
2 Michot, G; Chamdier, G. Physical Metallurgy of RS/PM Aluminum alloys, invited paper presented at ICAA2, Oct, 1990, Beijing, P. R. China.
3 Li, Qingchun *et al.* Materials Science and Engineering, 1992, (3): 15.
4 Chen, Zhenhua *et al.* CN88212137.5, 1988.
5 Chen, Zhenhua *et al.* CN90106130.1, 1990.
6 Shigenori, Yamauchi; Kazuhisa, Shibue *et al.* 住友轻金属技报, 1988, (10): 16.
7 Cao, Naiguang(ed). Plastic Working Theory of Metals. Beijing: Metallurgical Industry Press, 1986.
8 Laue, K; Stengeri, H. Extrusion, ASM 1981.