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Effects of misch metal addition on the hot plasticity of an Al–Mg–Si wrought alloy

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Abstract

A systematic investigation has been made of the effects of misch metal addition on the hot plasticity of an Al–Mg–Si alloy containing 0.75% Mg and 0.39% Si by using a hot torsional test, and the mechanism of these effects examined by means of scanning and transmission electron microscopy. The results show that the hot plasticity of the alloy is obviously improved at 480–560 °C by addition of 0.16% misch metal. For this reason the homogenization process of the Al–Mg–Si–RE alloy RE6063 can be eliminated.

1. Introduction

Extensive investigations on the hot deformation of aluminium and its alloys have been carried out by many investigators [1–9]. The hot deformation parameters of these materials, *e.g.* the extrusion force at a given reduction ratio and extrusion rate, the reduction ratio and extrusion rate before surface failure occurs or the hot plasticity and hot deformation resistance at a given strain rate, have been correlated with deformation temperature, alloy composition and heat treatment procedures [6–9]. However, in the past, composition effect investigations were mainly focused on the alloying elements silicon, magnesium, iron, zinc and copper, and only limited efforts were made to study the effects of minor additions such as rare earths. Although the application of rare earth elements in aluminium alloys has been fairly successful and a lot of investigations have been carried out [10, 11], only a few wrought aluminium alloys containing rare earth additions have been brought into production. RE6063 alloy, an Al–Mg–Si–RE alloy, is one of these [12]. In this paper the effects of misch metal addition on the hot plasticity and extrusion performance of 6063 aluminium alloy are investigated.

2. Experimental details

The tested alloys were produced by semicontinuous casting to billets of 165 mm diameter which were machined to the desired specimens or heated to 560 °C for 7 h for homogenizing and then machined to test

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specimens. The misch metal used contained 45%–50% Ce, 25%–30% La, 10%–12% Nd and other rare earth elements. The chemical composition of the alloys is given in Table 1.

The hot deformation characteristics were measured by means of the hot torsional test because the torsional deformation is similar to the extrusion deformation. The torsional cycle number (N_f) up to which the alloys began to fracture was considered to reflect the hot plasticity. A schematic diagram of the sample for hot torsional testing is given in Fig. 1. The hot deformation was carried out at 440, 480, 520 and 560 °C at strain rates of 0.109–0.435 s^{-1}. Before deformation the specimens were heated to the test temperature and then held there for 10 or 60 min. The microstructure of the alloys was observed by means of scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

3. Results and discussion

3.1. Effects of misch metal addition on the hot plasticity

For a constant strain rate of 0.109 s^{-1} the effects of misch metal addition on the hot plasticity of the alloy are shown in Fig. 2. The results show that the two groups of curves pertaining to heating for 10 and 60 min respectively follow exactly the same pattern, which indicates that there is a relationship between the hot plasticity (N_f) and the deformation temperature. In other words, all N_f values obtained in the experiments remain almost constant up to 480 °C, beyond which they rise rapidly with increasing temperature. When the deformation temperature is lower than 480 °C, the N_f values increase slightly with addition of rare earth metal. Once the temperature rises above 480 °C, the N_f values increase distinctly with misch metal addition. For example, the misch metal addition enhances the N_f values by about a factor of 2 at 520 °C for the homogenized alloys. It is found from Fig. 2 that the rare earth addition yields a much more effective improvement in hot plasticity

TABLE 1

Composition (weight per cent) of tested alloys

Alloy	RE	Mg	Si	Fe	Ni
6063	0	0.75	0.39	0.20	0.079
RE6063	0.16	0.75	0.38	0.20	0.079

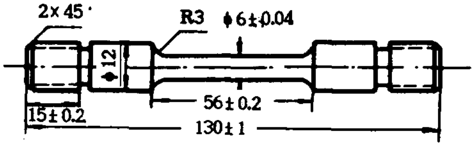

Fig. 1. Schematic diagram of specimen for hot torsional test.

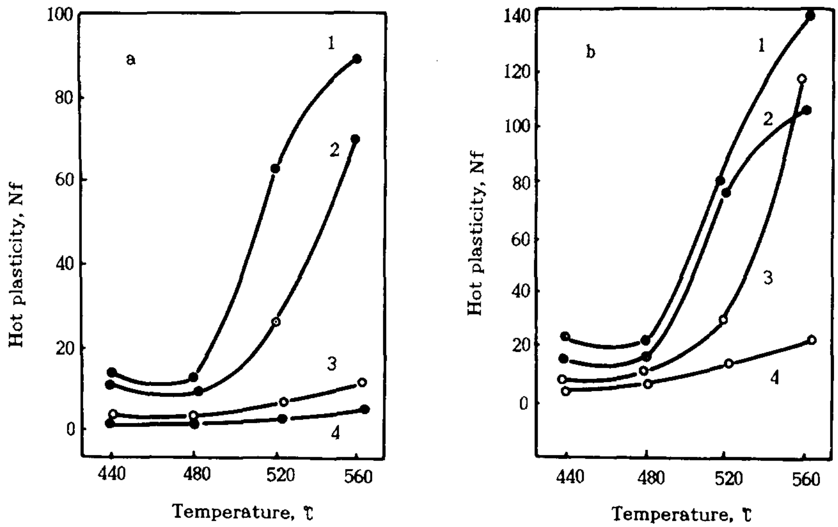

Fig. 2. Effect of misch metal on hot plasticity of 6063 alloy ($\epsilon = 0.109\ s^{-1}$): (a) 10-min heating; (b) 60-min heating; 1, RE6063 as annealed; 2, 6063 as annealed; 3, RE6063 as cast; 4, 6063 as cast.

in the homogenized alloys than in the unhomogenized alloys if the heating time is only 10 min. The increase in hot plasticity in the homogenized alloys by misch metal addition, however, is not so apparent as in the unhomogenized alloys if the heating time is increased to 60 min; that is, the longer the heating time, the more beneficial effects can be obtained by adding rare earths to the unhomogenized alloys, and at 520–560 °C the hot plasticity of the unhomogenized alloy RE6063 is two to six times as large as that of the unhomogenized alloy 6063 if the heating time is 60 min. In fact, the N_f value for the unhomogenized alloy RE6063 heated for 60 min is about twice that for the annealed alloy 6063 heated for 10 min. In some factories in China the actual heating time before hot deformation is more than 60 min, so that the homogenization annealing process for the RE6063 alloy can be eliminated as a result of the addition of rare earth metal.

For a constant deformation temperature of 520 °C and a heating time of 10 min, the effects of misch metal addition on the hot plasticity with variation in strain rate from 0.109 to 0.435 s^{-1} are shown in Fig. 3. In the range 0.109–0.435 s^{-1} the effects of the rare earth addition on the N_f values of the tested alloy are of minor importance; that is, the N_f values increase slightly for the unhomogenized alloys and increase by approximately a factor of 2 for the homogenized alloys by adding misch metal.

The relationship between the N_f value and the maximum extrusion ratio λ_{max} can be expressed by

$$\lambda_{max} = \exp\left(\frac{\pi d N_f}{L 3^{1/2}}\right)$$

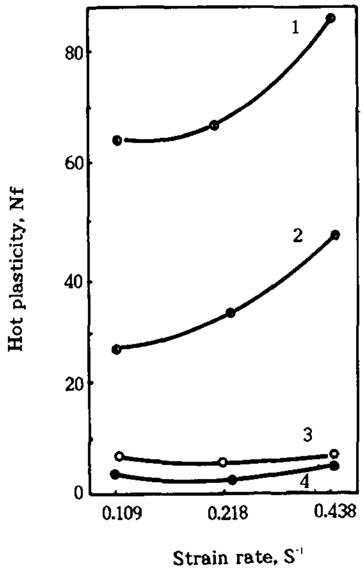

Fig. 3. Effect of misch metal on hot plasticity with a deformation temperature of 520 °C and a heating time of 10 min: 1, RE6063 as annealed; 2, 6063 as annealed; 3, RE6063 as cast; 4, 6063 as cast.

where d is the diameter, and L the length of the deformation zone for the hot torsional specimens.

It can be seen from the above equation that a small increase in N_f value can result in a very apparent increase in λ_{max} ratio. Hence the rare earth addition can distinctly increase the λ_{max} ratio of the tested alloys owing to the great improvement in hot plasticity resulting from misch metal addition (Figs. 2 and 3).

3.2. Microstructures of the tested alloys

The microstructures of the tested alloys, as cast and annealed, were examined by means of optical microscopy, SEM and TEM. The as-cast and homogenized microstructures of the alloys are given in Figs. 4 and 5 respectively and the morphology of some constituent phases containing iron in Fig. 6. The results revealed that the as-cast microstructure of the alloy was refined, the secondary dendrite arm spacing decreased by about 20%, the morphology of the coarse constituent phases improved and the formation of needle-shaped precipitates in annealed alloys was inhibited by addition of misch metal. A more detailed investigation has been described in the authors' recent publication [12]. It is these improvements mentioned above that enhance the hot plasticity of the tested alloys.

3.3. Effect of misch metal addition on the extrusion performance

On the basis of the experimental results obtained in our laboratory, an industrial test was carried out in order to determine whether the annealing process for homogenization may be eliminated. The results are given in Table

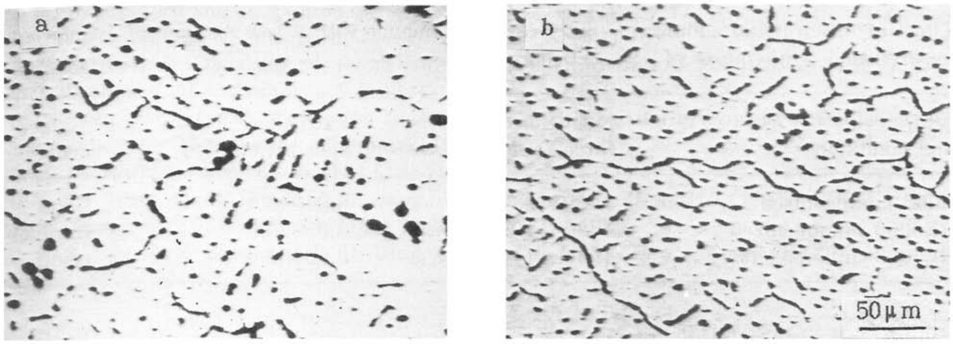

Fig. 4. Effect of misch metal on as-cast microstructure: (a) 6063; (b) RE6063.

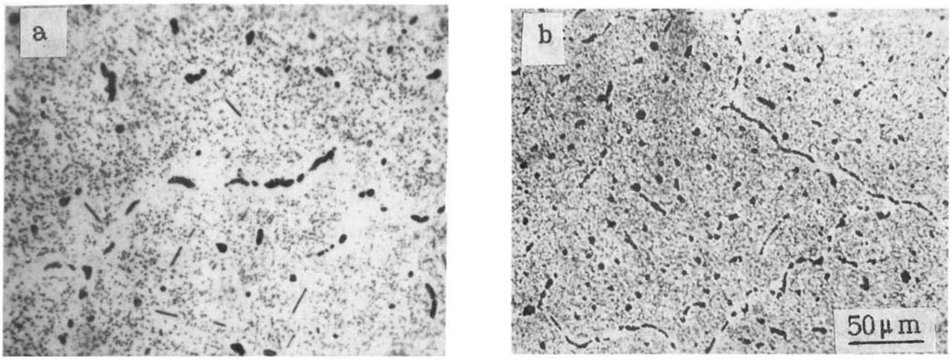

Fig. 5. Effect of misch metal on homogenized microstructure: (a) 6063; (b) RE6063.

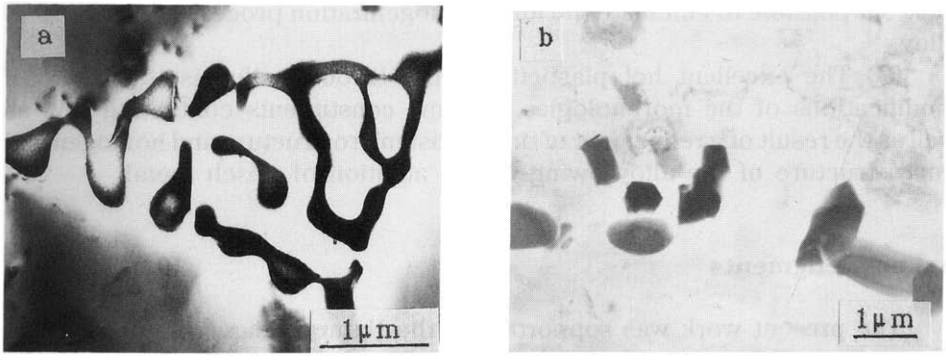

Fig. 6. Effect of misch metal on constituent phases containing iron in 6063 cast alloy: (a) without RE addition; (b) with RE addition.

2. It can be seen that the extrusion press force and extrusion speed for the unhomogenized RE6063 alloy are approximately the same as these for the homogenized 6063 alloy, and the product surface of the unhomogenized RE6063 alloy is of good quality. This suggests that the annealing process

TABLE 2

Effect of misch metal addition on extrusion performance with a heating time of 10 min and an extrusion temperature of 480–520 °C

Alloy and condition	Extrusion press force (N cm^{-2})	Extrusion speed (mm s^{-1})	Surface quality
6063 homogenized	1460–1080	3.64–4.20	Good
RE6063 homogenized	1480–1100	3.95–4.20	Excellent
RE6063 unhomogenized	1530–1110	3.80–3.90	Good

may be eliminated owing to the greater improvement in hot plasticity obtained by adding misch metal if only the extrusion process is considered.

In fact, various measurements of the mechanical, physical and chemical properties of the profile alloys have shown that most of these properties of the unhomogenized RE6063 alloy are better than those of the homogenized 6063 alloy.

4. Conclusions

(1) The hot plasticity of the 6063 alloy, unhomogenized or homogenized, is distinctly improved in the range 480–560 °C by adding 0.16% misch metal. If a deformation temperature of 520 °C and a heating time of 10 min are chosen, the hot plasticity of the homogenized 6063 alloy is increased by about a factor of 2; if 560 °C and 60 min are chosen, the hot plasticity of the unhomogenized 6063 alloy is increased more than five times.

(2) The apparent improvement in hot plasticity by misch metal addition makes it possible to eliminate the long homogenization process of the RE6063 alloy.

(3) The excellent hot plasticity of the RE6063 alloy is the result of modifications of the morphologies of some constituents containing iron as well as the result of a refinement of the as-cast microstructure and homogenized microstructure of the alloy owing to the addition of misch metal.

Acknowledgments

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