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EFFECT OF DISPERSOID Al_3Ni ON MECHANICAL PROPERTIES AND TEXTURE IN EXTRUDED Al-Ni ALLOYS

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Abstract

The strengthening mechanism of a dispersion strengthened alloy is strongly related to such metallurgical parameters as particle size, volume fraction of particles, interparticle spacing and grain size. Such relationships are described in extruded Al-Ni alloys containing fine eutectic particles and coarse primary particles.

The theoretical values derived from the shear-lag theory and Orowan strengthening are not in agreement with the observed strength. The grain size should also be taken into account.

The effects of particles on the microstructure arise either from the presence of nucleation site at the coarse particles or the pinning of grain boundaries due to the fine particles. The recrystallization behavior is investigated using a textural observation by changing the dispersion parameters. The coarse particles weaken the deformation texture. The relationships between the texture and the dispersion parameters are discussed.

Introduction

In the Al-Ni eutectic alloy, it is well known that the tensile strength is increased by the presence of intermetallic compound Al_3Ni. There are various types of materials strengthened by fibers which are obtained by unidirectional solidification, fine particles uniformly aligned in the deformation direction[1] and very fine grains by pinning the grain boundaries with a uniform dispersion of fine particles[2].

There are a great number of reports which attempt to explain the influence of the hard-dispersed phase regarding these mechanical properties. Concerning the dispersion strengthened alloys, however, the influence of particles on the formation of microstructures has not been sufficiently considered, in spite of having relationship to the mechanical properties[2].

Al-Ni eutectic alloy containing 5wt.%Ni has fine particles and hypereutectic alloys containing 10 to 20wt.%Ni have coarse as well as fine particles. The object of this study is to investigate the influence of the dispersion parameters in the extruded Al-Ni alloys on the mechanical properties and the formation of microstructures.

Coarse primary particles appearing in the hypereutectic alloys are detrimental to the mechanical properties of these alloys. So, the authors have proposed a new method[3] capable of using the merits of mass production. The new method consists of high-pressure casting with a high-cooling rate and extrusion causing very strong hot deformation. As a result of this method, Al-Ni alloys strengthened by finer particles uniformly dispersed in the matrix were prepared.

Experimental

Commercial pure aluminum (99.7wt.%) and Al-30wt.%Ni master alloy were used to prepare Al-Ni alloys containing 0, 5, 10, 15 and 20 wt.%Ni. The alloys were cast under 130MPa in a metal mold. Each billet had a dimension of 70(D)×150(L)mm. The cooling rate in the central region of the billet was 23°C/sec, which was determined using a thermocouple. The billets were extruded at 500°C into a 12(D)mm rod at a speed of 0.017m/s. The mean strain rate calculated using Faltham's equation[4] was 0.24 sec^{-1}. The extrusion ratio expressed by the ratio of the sectional area of billet before and after extrusion was 34.

Room temperature tensile tests were carried out at a strain rate of 0.07sec^{-1} using specimens with a 50mm gauge length. Microstructures were observed by a polarized light microscope and a transmission electron microscope (TEM) on a section parallel to the extrusion direction. The dispersion parameters of particles were measured by a computerized image analyzer. These results are shown in Table 1. The specimens for the pole figure measurement were prepared from a central region parallel to the extrusion direction. The complete pole figures (111) and (200) were determined using CuKα radiation, and the date of these pole figures were used for calculating the orientation distribution functions (ODFs) and inverse pole figures.

Table 1 Particle dispersion parameters and grain diameter of Al-Ni alloys

Ni content (wt.%)	Eutectic			Primary			D (μm)
	d (μm)	λ (μm)	V_f (%)	*d* (μm)	λ (μm)	V_f (%)	
5	0.5	2.5	11.7	—	—	—	5
10	1.4	8.0	10.4	21.5	272.3	5.0	7
15	1.6	10.4	9.3	31.0	75.5	21.5	10
20	1.5	11.0	8.3	41.5	47.1	37.0	10

d Mean particle diameter
λ Mean free path
$= \frac{2d}{3V_f}(1-V_f)$ Fullman's equation[5]
V_f Volume fraction of particles
D Mean grain diameter

Results and Discussion

Mechanical Properties

The effect of the variable content of Ni on the mechanical properties of extruded Al-Ni alloys is shown in Fig. 1. The yield strength increases with the Ni content while the ultimate tensile strength reaches its maximum at 10wt.%Ni. The elongation decreases as the Ni content increases.

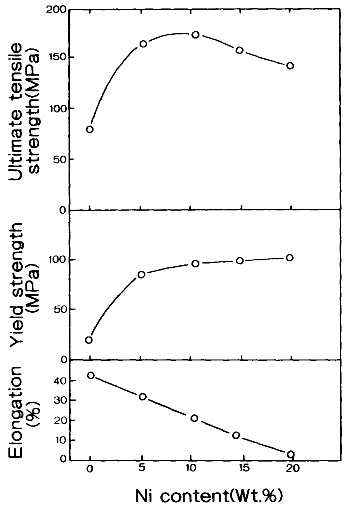


Fig. 1 Mechanical properties of Al-Ni alloys

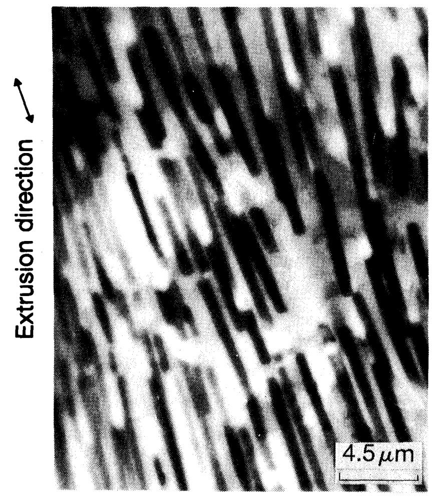


Fig. 2 TEM micrograph of Al-5wt.%Ni on a section parallel to extrusion direction.

A TEM micrograph of the Al-5wt.%Ni alloy containing fine rod-like particles with a mean size of $0.5(D)\times5(L)\mu m$ is shown in Fig. 2. The fine particles are aligned in the extrusion direction. In general, the shear-lag theory and the Orowan strengthening mechanism may be used to predict the strength of the alloy.

Nardone et al.[6] have offered the modified shear-lag theory

$$\sigma_{CY} = \sigma_{MY}\,(1+\frac{1}{2}\cdot\frac{l}{d}\cdot V_f) \qquad (1)$$

accounting for yield strength of the whisker strengthened composite, where σ_{MY} is the yield strength of the matrix, l the fiber length, d the fiber diameter and V_f the fiber volume fraction. Typical values for the Al-5wt.%Ni alloy would be σ_{MY} = 20MPa, l = 5.0μm, d = 0.5μm and V_f = 0.117. The yield strength of the alloy is calculated to be 32MPa.

In the case of the Orowan strengthening mechanism, the particle by-passing stress τ for particles with an appreciable aspect ratio can be calculated from the modified Orowan relation[7]

$$\tau = \frac{0.83Gb}{2\pi\,(1-\nu)^{1/2}}\;\frac{1+l/L}{L}\;ln\left(\frac{d}{\gamma_0}\right) \qquad (2)$$

where G is the shear modulus of the matrix (28GPa), b the Burger's vector (0.286nm), ν the poison's ration (0.3), l the particle length, L the planar interparticle spacing $(ld/V_f)^{1/2}$, d the particle diameter and γ_0 the inner cut-off radius of the dislocation (4b). The typical values would be l = 5.0μm, d = 0.5μm and L = 4.6μm. The particle by-passing stress is calculated to be 6.5MPa. The yield strength of the alloy is calculated to be 33MPa.

In contrast, the observed yield strength is 90MPa. It is unlikely that consideration of dispersion strengthening could account for the very large difference between the observed and calculated values. Morris et al.[8] are of the opinion that the relationship between yield strength and grain size in the Al-6wt.%Ni alloy can be described by the Hall-Petch relationship

$$\sigma_Y = 47 + 157D^{-1} \qquad (3)$$

where D is the grain size. The grain size can not be determined exactly as mentioned below, then, assuming of D = 5μm, the calculated value for σ_Y is 78MPa. This value is more similar to the observed strength than that predicted from the shear-lag theory and the Orowan's strengthening mechanism. The grain size in the Al-5wt.%Ni alloy with fine grains is considered to play an important role in the strengthening mechanism.

In the case of the alloy containing more than 5wt.%Ni, Eq. (1), where the yield strength of the matrix would be that of Al-5wt.%Ni alloy (90MPa) and the aspect ratio of coarse particles would be 1, is close to the observed values as shown in Fig. 3. The yield strength increase by the coarse primary particles should then represent the shear-lag contribution to strengthening. Further experiments are planned to test this hypothesis.

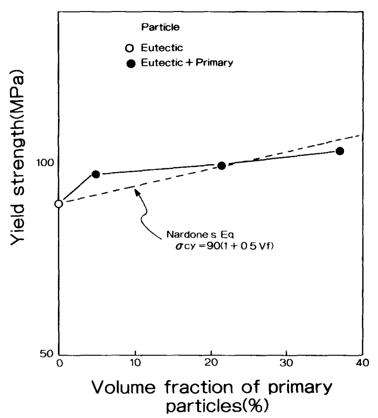
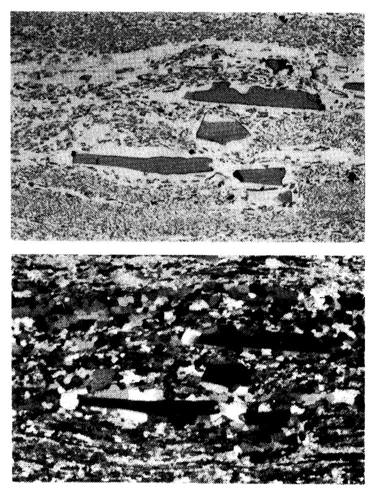


Fig. 3 Effect of volume fraction of primary particles on the yield strength in Al-Ni alloys.



(a) Particles dispersed structure

80 μm

(b) Grain structure

Fig. 4 Microstructures of Al-10wt.%Ni alloy

Microstructure

The microstructure of the specimen containing 5wt.%Ni shows extremely finer microstructure than that of the Ni-free alloy (220μm). The fine particles, whose diameter is 0.5μm as shown in Table 1, impede grain growth, therefore, the grains are extremely fine and can't be seen optically in some regions associated with the interdendritic network of the Al-Al_3Ni eutectic.

In the case of hypereutectic alloys, containing both fine and coarse particles, the recrystallization behavior is rather complex. This is related to the influence of the coarse particles, on the deformation structure. The uniform structure is destroyed in the vicinity of the coarse undeformable particles as shown in Fig. 4. The grain diameter of the region, lacking fine particles in the vicinity of the coarse particles, is larger than that of the region having fine particles of a high density.

As seen in Table 1, the mean particle diameter in the eutectic alloy is 0.5 μm, while that of eutectic particles in the hypereutectic alloys is about 1.5 μm. The difference between 0.5 and 1.5μm is a very important, since it has been mentioned that fine particles (<1 μm dia.) inhibit both grain nucleation and growth rate while coarse particles (>1 μm dia.) stimulate the nucleation rate by acting as nucleation sites. Also, the mean free path of the fine particles in eutectic alloy is closer than that in hypereutectic alloys. Therefore, the grain size of hypereutectic alloys is larger than that of eutectic alloy.

To obtain the fine grain structure of extruded aluminum alloy, it can be seen that the dispersed particles with a size ranging from 0.5 to 1.5 μm in diameter and close mean free path of less than about 10 μm are required.

Texture

To find the effect of particles on the change in the microstructure, ODF analysis was carried out. In Fig. 5, the effect of variable amounts of Ni on the change in the texture of the Al-Ni alloys is shown. The texture of the Al-Ni alloys consists of <111> and <100> components. These two components decrease with the Ni content in the Al-Ni alloys. The Al-Ni alloys containing more than 10wt.%Ni show a random texture.

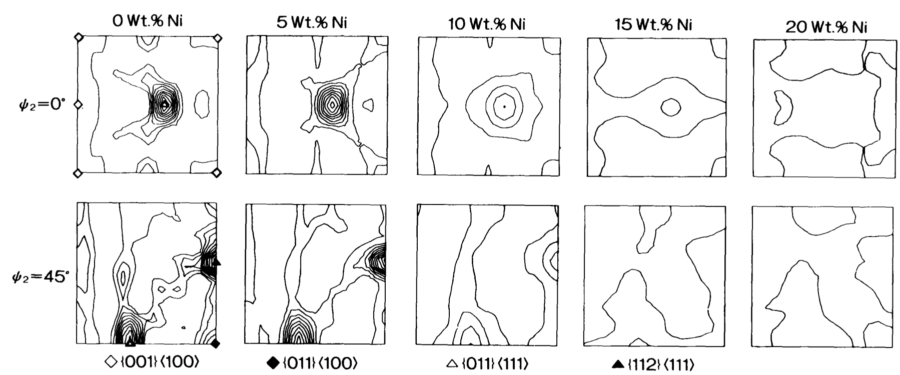


Fig. 5 $\phi_2=0°$ and $\phi_2=45°$ sections in ODFs of Al-Ni alloys

The quantitative changes in the orientations which are derived from the inverse pole figures are shown in Fig. 6. This figure represents that the texture has significantly changed at 10wt.%Ni. At 5wt.%Ni the <111> component is retained and the <100> component decreases. This may be explained by the pinning of the grain boundaries by the fine particles. The development of the <100> component during recrystallization is smaller than in Ni-free alloy without fine particles.[9] At 10wt.%Ni coarse primary particles appeared in the microstructure. It can be seen that these coarse particles affected the formation of the random texture. This may be mainly due to the fact that the coarse particles developing the deformation zone during the extrusion process enhance the generation of the recrystallization nucleis which show a random orientation.

To get a better understanding of the formation of the random texture with respect to particles dispersion, the relationship between the orientation density and the mean free path to size ratio of the coarse particles is shown in Fig. 7. This figure shows that the densities of the <111> and <100> components decrease as the mean free path to size ratio of the coarse particles increases. It is found that the random texture is formed at the mean free path which is of the order of the particle diameter.

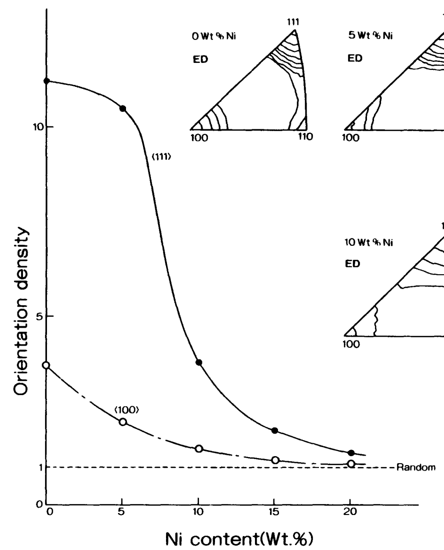


Fig. 6 <111> and <100> orientation densities derived from inverse pole figures of Al-Ni alloys

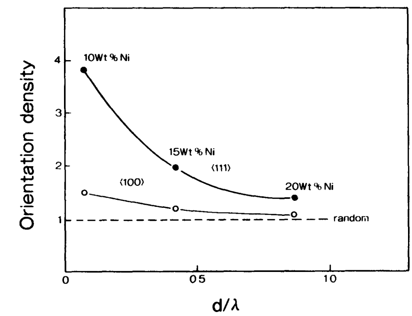


Fig. 7 <111> and <100> orientation densities as a function of $d \cdot \lambda^{-1}$ where d is coarse particle diameter and λ is mean free path

Conclusions

The grain size in the Al-5wt.%Ni alloy containing fine rod-like particles is considered to play an important role in the strengthening mechanism. The yield strength increase due to coarse primary particles is explained by Nardone's modified shear-lag theory.

The development of the microstructure is significantly affected by dispersion parameters. The fine grain structure is formed in the Al-Ni alloys containing fine particles with a size ranging from 0.5 to 1.5μm in diameter and close mean free path of less than about 10μm. The coarse particles weaken the deformation texture consisting of <111> and <100> components. And, the random texture is formed at the mean free path which is of the order of the particle diameter.

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