

## Effect of eutectic phase on damping and mechanical properties of as-cast Mg-Ni hypoeutectic alloys

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**Abstract:** Dynamic mechanical analysis (DMA) was applied to systematically investigate the low frequency damping properties of as-cast hypoeutectic Mg-Ni alloys. The results show that the as-cast hypoeutectic Mg-Ni alloys exhibit high damping capacities. The strain amplitude dependent damping curve has its own special characteristic, in which the damping is strongly related to the strain amplitude. The effect of the eutectic phase on damping and the mechanical properties of as-cast hypoeutectic Mg-Ni alloys were also discussed in detail.

**Key words:** Mg-Ni hypoeutectic alloys; strain amplitude dependence; damping properties; mechanical properties; eutectic phase

### 1 Introduction

Magnesium and its alloys have promising properties of low density, good machinability and recycleability, etc[1] and are regarded as the advanced structural metallic materials. Recently, magnesium and its alloys are applied in the automobile, electric industrial and aviation industries[1]. Moreover, it is necessary to point out that magnesium and its alloys also have excellent damping properties, which makes magnesium alloys the promising candidates to meet the need of the high damping alloys.

In the past few years, Mg-Ni alloys were found to exhibit high damping as well as good mechanical properties[2]. More recently, a damping peak around 100 °C was newly detected by HU et al and the stability of this peak was discussed[3]. As we know, the microstructure of as-cast hypoeutectic Mg-Ni alloys consists of  $\alpha$ -Mg solid solution and eutectic phase ( $\alpha$ -Mg+Mg<sub>2</sub>Ni), and the eutectic phase is an important factor of the overall damping capacity of magnesium alloys. However, up to now, there is very few literature about the effect of eutectic phase on the damping and mechanical properties for hypoeutectic Mg-Ni alloys. Thus, in this work, we systematically study the effect of

eutectic phase on the damping capacity as well as the mechanical properties of hypoeutectic Mg-Ni alloys.

### 2 Damping characterization

In this study, the measure of damping capacity utilized is loss tangent  $\tan \phi$ , which is measured using dynamic mechanical thermal analysis (DMA). A sample installed in the DMA testing head, was constrained at each end by a clamping bar arrangement with one end fixed to a rigid frame and the other end driven by an electromagnetic vibrator via a composite drive shaft. The resulting sinusoidal force and deflection data were recorded and analyzed by modulus. The calculation of the loss tangent and dynamic modulus is based on the following forced vibration equation[4]:

$$M \frac{dx^2}{dt^2} + (\eta_v + \frac{S''}{\omega} + \frac{kE''}{\omega}) \frac{dx}{dt} + (S' + kE')x = F_p \sin(\omega t) \quad (1)$$

where  $M$  denotes the vibrating system mass;  $\eta_v$  is the viscous damping term,  $S'$  and  $S''$  represent the complex stiffness of the suspension which serve as calibration terms for the system;  $k$  is the sample geometry factor; both  $E'$ , storage or dynamic modulus, and  $E''$ , loss modulus, refer to the real and imaginary parts of the

complex modulus of specimen, respectively;  $x$  is the deflection at the driven end of the sample at which the external force,  $F_p \sin(\omega t)$  is applied. The DMA gives rise to the solution to  $kE'$  and  $kE''$ . The damping capacity, in terms of loss tangent is calculated according to

$$\tan \phi = \frac{kE''}{kE'} = \frac{E''}{E'} \quad (2)$$

### 3 Experimental

The materials of as-cast hypoeutectic Mg-Ni alloys were prepared by melting pure Mg and Mg-30%Ni master alloys in resistance furnace at 700 °C and poured into a steel-mold under the CO<sub>2</sub>/0.5%SF<sub>6</sub> gas protection. The as-cast ingots were then cooled in the protective gas. Rectangular bending beam specimens for damping measurements with dimensions of 50 mm×5 mm×1 mm were machined out using an electric spark cutting method. The damping tests were carried out using a Mettler Toledo DMA 861. Strain dependent damping tests were made at various maximum strains ( $\varepsilon_{\max}$ ) from  $1 \times 10^{-6}$  to  $1 \times 10^{-3}$  and the frequency was held at 1 Hz. The microstructures were examined by SEM using backscattering electron image.

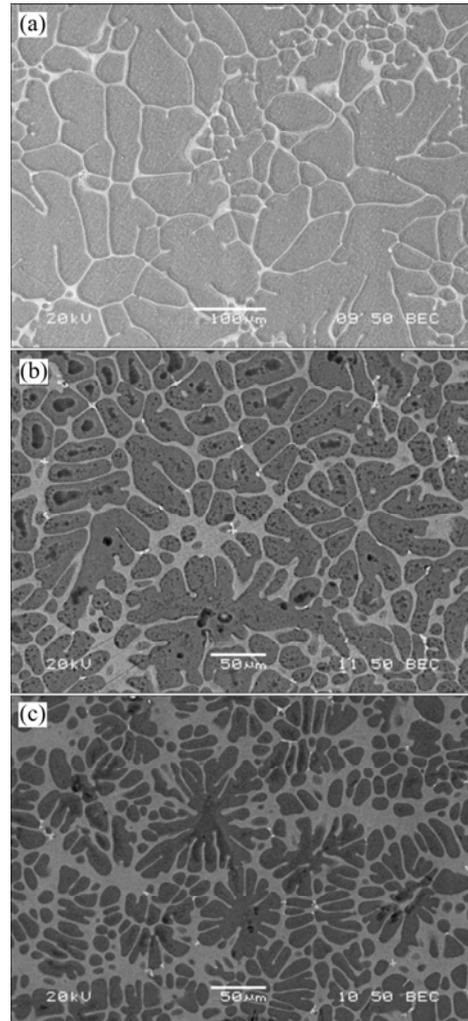
## 4 Results

### 4.1 Microstructure

Fig.1 shows the SEM microstructures of the Mg-Ni hypoeutectic alloys with different Ni contents of 3%, 6% and 10%(mass fraction). According to the Mg-Ni binary alloy phase diagram[5], at the first eutectic point, Ni content is 23.5%, so the tested alloys have the composition all within hypoeutectic composition. The  $\alpha$ -Mg+Mg<sub>2</sub>Ni eutectic phases are dispersive in the  $\alpha$ -Mg interdendrites. In addition, it is necessary to point out that in terms of the phase diagram Ni has quite low solute ability in the  $\alpha$ -Mg dendrite. The low solubility is an important factor for the high damping properties of Mg-Ni series hypoeutectic alloys according to the mechanism involving the interaction between the dislocation and solute atoms[6]. As shown in Fig.1, the dimension of the  $\alpha$ -Mg dendrites is obviously refined by increasing Ni content. The eutectic phase markedly increases with the increase of Ni content. The calculated eutectic phase content is listed in Table 1.

**Table 1** Composition and corresponding eutectic phase content of Mg-Ni alloy

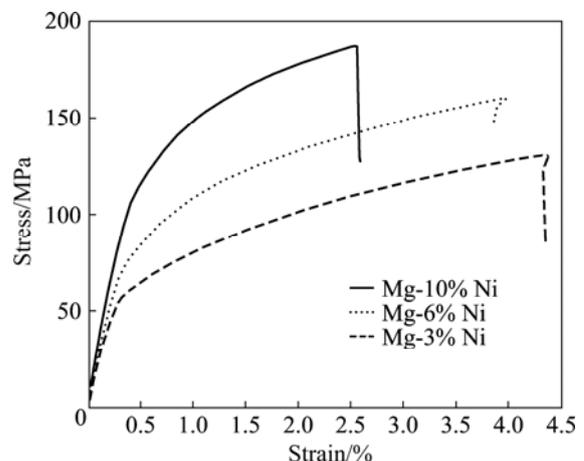
Composition	Volume fraction of eutectic phase/%
Mg-3%Ni	12
Mg-6%Ni	24
Mg-10%Ni	42



**Fig.1** Microstructures of as-cast hypoeutectic Mg-Ni alloy with different Ni contents: (a) Mg-3%Ni; (b) Mg-6%Ni; (c) Mg-10%Ni

### 4.2 Mechanical properties

Fig.2 shows the tensile curves of Mg-Ni hypoeutectic alloys with different Ni contents. Table 2



**Fig.2** Room temperature mechanical properties of as-cast hypoeutectic Mg-Ni alloy with different Ni contents

**Table 2** Mechanical properties of as-cast hypoeutectic Mg-Ni alloys

Alloy	Yield strength /MPa	Tensile strength /MPa	Elongation /%	Elastic modulus /GPa
Mg-3%Ni	63.3	130.6	4.3	42
Mg-6%Ni	84.9	160.6	3.8	46
Mg-10%Ni	119.5	187.7	2.5	48

lists the details of mechanical properties of the as-cast hypoeutectic Mg-Ni alloys. The results show that the as-cast Mg-Ni hypoeutectic alloys exhibit good mechanical properties. The true tensile strength and elastic modulus increase with the increase of Ni content, while the ductility decreases. The high tensile strength as well as high elastic modulus of high Ni contained alloys is ascribed to the refinement of  $\alpha$ -Mg dendrites and the increase of eutectic phase. The decrease of ductility is apparently due to the increase of volume fraction of the brittle phase of  $Mg_2Ni$ .

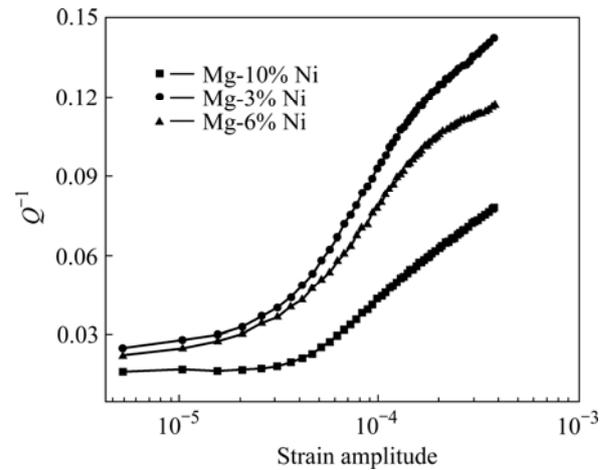
#### 4.3 Damping capacities of as-cast hypoeutectic Mg-Ni alloys

Fig.3 shows the damping capacities of as-cast hypoeutectic Mg-Ni alloys as a function of strain amplitude. The damping values in the current strain amplitude range ( $1 \times 10^{-6} - 1 \times 10^{-3}$ ) are all larger than 0.01 (it is usually considered if damping value is larger than 0.01, the material exhibits high damping characteristic), which indicates that the as-cast hypoeutectic Mg-Ni alloys are high damping alloys. According to the curves, it is necessary to note that the damping capacities are strongly dependent on the strain amplitude, and the weakly dependent parts hardly appear, which is different from the strain amplitude dependent curves obtained in another as-cast magnesium alloys, such as AZ91 alloys[7]. The reason for this strong dependence, on the one hand, is possibly due to the fact that too large strain amplitude is used here, which makes the detection of the strain weakly dependent part impossible; on the other hand, is possibly due to the intrinsic property of high damping material. Furthermore, it is interesting to note that, more than one damping plateau appear in Fig.3 (e.g. curves for Mg-3%Ni or Mg-6%Ni). The similar case was found in as-cast high damping Mg-Si alloys[8]. The authors ascribed it to the breakaway of different dislocations system (screw-edge system and edge system) from solute atoms. The more details could be seen in Ref.[9].

## 5 Discussion

### 5.1 Effect of eutectic phase on mechanical properties

In the case of a material containing multiple phases,

**Fig.3** Strain amplitude dependent damping of as-cast hypoeutectic Mg-Ni alloy with different Ni contents

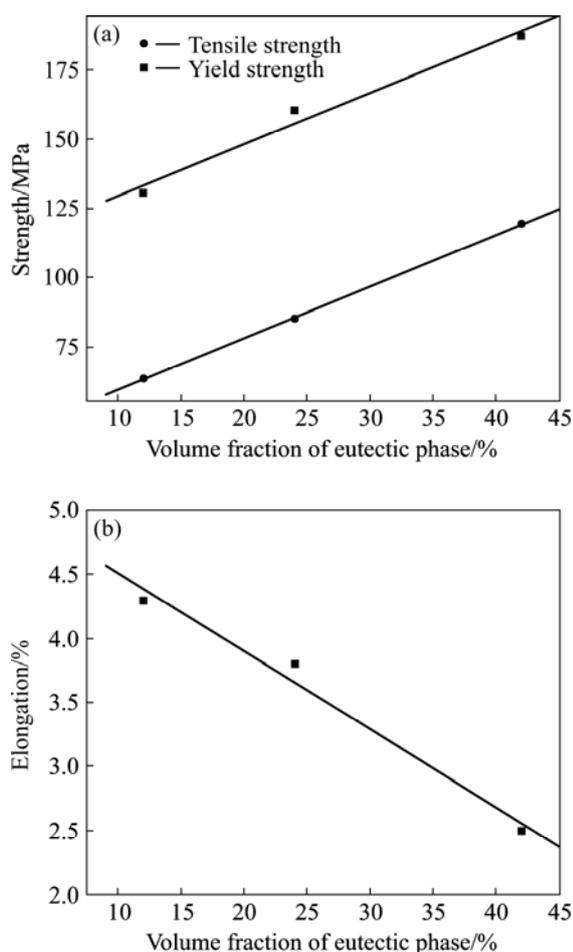
the overall mechanical properties are intimately coupled to those of the individual components. Accordingly, it is often useful to apply a rule of mixtures (ROM) approach to gain insight into the effect of a particular component[4]. As it referred above, the  $\alpha$ -Mg dendrite, and the laminar eutectic phase ( $\alpha$ -Mg+ $Mg_2Ni$ ) are comprised of the hypoeutectic alloys. Hence, the following equation can be used to describe the ROM in Mg-Ni alloys.

$$M_c = \eta_e \phi_e + \eta_d (1 - \phi_e) \quad (3)$$

where  $M_c$  is the mechanical property of the alloy;  $\eta_e$  and  $\eta_d$  denote the mechanical capacities of the eutectic phase and the  $\alpha$ -Mg dendritic phase, respectively;  $\phi_e$  is the volume fraction of the eutectic phase. Fig.4 shows the relationship between the volume fraction of eutectic phase and the mechanical properties of as-cast hypoeutectic Mg-Ni alloys. We can see that the fitted data are well accorded with linear relationship, which confirms that the effect of eutectic phase on the mechanical properties yields to ROM.

### 5.2 Effect of eutectic phase on damping properties

The presence of the eutectic phases introduces a number of changes in the microstructure in terms of interfaces and dislocations and hence leads to a change in the overall damping behavior of alloys. Thus, it is necessary to study the effect of eutectic phase on the damping properties of Mg-Ni hypoeutectic alloys in detail. Eutectic phases influence the damping behaviors of alloys by the following possible mechanisms[4]. First, the interfaces between primary phase and eutectic phases dissipate energy under cyclic loading; however, it usually occurs in the weaker interface band, such as in some ceramic reinforced metal matrix composites[10–12]. In



**Fig.4** Relationship between volume fraction of eutectic phase and mechanical properties of as-cast hypoeutectic Mg-Ni alloys

terms of Mg-Ni alloys, the energy dissipation on interface under cyclic loading can be neglected at room temperature, because if the interface markedly causes the energy dissipation, the Mg-10%Ni alloy with a high level of eutectic phase could exhibit high damping. In fact, the experimental results are contradictory to above analysis. Second, the dislocations are anchored at the interface of eutectic phase. Third, the eutectic phase may possess different intrinsic damping from the primary phase and thereby lead to a rule of mixture effect on the overall damping behaviors[4].

Generally, the well accepted theory on the damping of magnesium alloys is G-L theory[13–14]. The G-L theory describes the pinned or unpinned dislocations to explain the anelastic energy loss. According to G-L dislocation pinning theory, the length of the dislocation line has a significant influence on unpinning of the dislocation lines from weak pinners. The longer the dislocation line, the easier the dislocation breaks away from weak pinners. Thus, the dislocation length distribution in the Mg-Ni alloys should be made into a detailed classification. Usually, the dislocations can

mainly be divided into three kinds. For the first case, it distributes in the primary  $\alpha$ -Mg dendrites with long dislocation lines, in which the dislocation is weakly pinned by solute atoms (Ni) or vacancies. The major strong pinners are the interfaces between primary  $\alpha$ -Mg dendrite and eutectic phase. This kind of long dislocation lines is easy to break away from the weak pinning points under external stress due to pure  $\alpha$ -Mg dendrites in Mg-Ni alloys, but difficult to break away from the anchored interfaces. Therefore, the  $\alpha$ -Mg dendrites size is a direct factor impacting the movement of dislocations by providing the maximal single dislocation length and the total length of the dislocations. For the second case, dislocation lines are in  $\alpha$ -Mg within the lamellar eutectic. These dislocation lines, anchored by the interface, are difficult to move. WELLER et al[15] found that the movement of dislocation lines anchored at both ends at the interface in laminar  $\gamma$ -TiAl can only be activated at high temperature. For the third case, the dislocation lines are distributed in  $Mg_2Ni$  phase within lamellar eutectic. These dislocation lines are very short and the poor mobility makes little contribution to the overall damping properties.

## 6 Conclusions

1) The hypoeutectic Mg-Ni alloys exhibit high damping capacity, which presents strong strain amplitude dependence. More than one damping plateau appear in high damping curves for Mg-3%Ni and Mg-6%Ni alloys.

2) The as-cast Mg-Ni alloys exhibit good mechanical properties. With the increase of Ni content, the true tensile strength as well as elastic modulus increases but the ductility decreases. The decreased ductility of the alloys is apparently due to the increased brittle  $Mg_2Ni$ . The effect of eutectic phase on the mechanical properties yields to a rule of mixtures.

3) There is no dissipation of energy on the interface within as-cast hypoeutectic Mg-Ni alloys under room temperature condition. The reduction of the damping value of high Ni contained alloy is due to the volume fraction and dimension reduction of  $\alpha$ -Mg dendrites.

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