Investigation on Damping Capacities of Spherical Mg_2Si Magnesium Matrix Composites Prepared by Super-Gravity Method

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Abstract. Due to inherent high damping capacities of Mg, Mg-based alloys or composites can absorb enormous elastic energy, thus, can be used as damping materials playing important role in reducing vibration and noise. Spherical Mg_2Si magnesium matrix composites were prepared by super-gravity method with fly ash floating beads with particle sizes of 80, 125 and 500 μm. The microstructures and damping capacities of prepared samples were discussed. Spherical and fragment-shaped Mg_2Si phases were observed in the matrix by SEM micrograph. Increasing particle size of fly ash floating beads can lead to an obviously decreasing tendency of internal friction $\tan\varphi$ .The critical strain ε_{cr} =1.9×10^{-2} of $\varepsilon-\tan\varphi$ curve and critical temperature T_{cr} =150 °C of $T-\tan\varphi$ curve for $\tan\varphi$ changing from slowly to greatly increasing. Damping peaks occur in the vicinity of strain ε =5.2×10^{-2} in $\varepsilon-\tan\varphi$ curve whereas no damping peaks occur in $T-\tan\varphi$ curve.

1 Introduction

Due to inherent high damping capacities of Mg[1], Mg-based alloys or composites can absorb enormous elastic energy, thus, can be used as damping materials playing important role in reducing vibration and noise. Relatively speaking, Mg-based composite material have better damping capacities due to either an addition of the second phase resulting in much more crystal defects, or inherent high damping capacities of the second phase itself, or absorption of vibration energy by phase interface[2,3]. The common preparation methods of Mg-based composite material are by usage of particles such as SiC, Al_2O_3, TiC_p particles and so on [4,5]. Liao *et al*.[6] successfully synthesized in-situ Mg_2Si/Mg-Al composites with Si particles, and obtained increasing Mg_2Si content can effectively increase the damping capacities of the composites. However, little hard research has been done on how the second phase with hollow spatial structure can influence the damping capacities of Mg-based composite material.

In the present work, in-situ spherical Mg_2Si magnesium matrix composites were successfully prepared in centrifugal apparatus by super-gravity method with hollow fly ash floating beads in sizes of 80, 125 and 500 μm, whose damping capacities has been investigated under conditions of changing temperature from ambient temperature T_{am} to 300 °C, strain ε from 1.0×10^{-3} to 1.0×10^{-1}.

2 Experimental

2.1 Preparation of Spherical Mg_2Si Magnesium Matrix Composites

Spherical Mg_2Si magnesium matrix composites were prepared in centrifugal apparatus in a type of DL-8M equipped with a heating furnace[7] using pure Mg ingot with 99.95 mass % purity and fly ash floating beads with particle sizes of 80, 125 and 500 μm shown in Figure 1..

The preparation procedures of spherical Mg_2Si magnesium matrix composites shown in Figure 2. can be summarized as follows: (1) Several pieces of magnesium about 30 g were placed into the upper graphite crucible and fly ash floating beads were placed into the lower one, where the upper and lower graphite crucible were tied together tightly as whole special crucible with substantial sieve pores between them[7]. Afterwards, the whole crucible were put in the heating furnace of the centrifugal apparatus; (2) The heating furnace was heated to 660 °C at a heating rate of 10 °C/min, and maintained for 10 min to ensure magnesium completely melted; (3) The whole crucible was rotated at a speed of 1338 r/min for

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promoting molten magnesium to percolate down through the sieve pores into the space among fly ash floating beads and their hollow space. During rotation process, the heating furnace was held at 660 °C for 1 min and then cooled to 600 °C; (4) The whole crucible including magnesium matrix composites sample was taken out from the heating furnace and then cooled to ambient temperature T_{am} in air atmosphere.

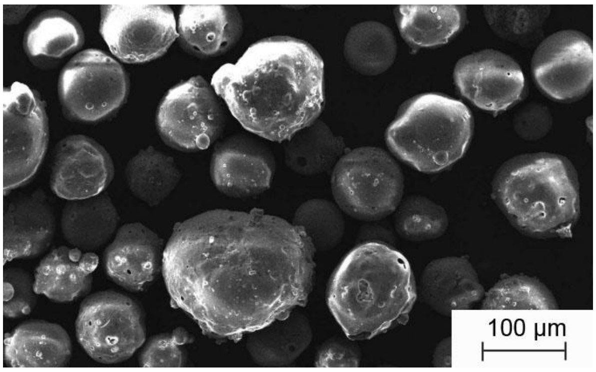

Figure 1. SEM micrograph of fly ash floating beads with particle sizes of 125 μm

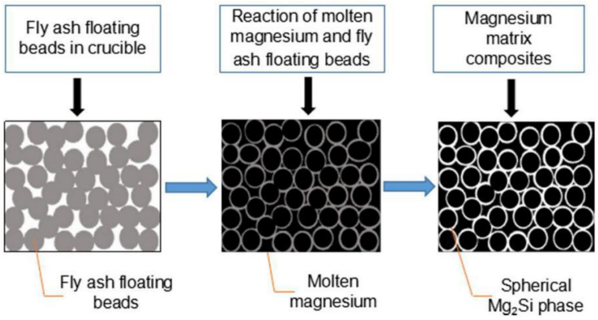

Figure 2. Preparation procedures of spherical Mg_2Si magnesium matrix composites by super-gravity method

2.2 Characterization of Microstructures and Damping Capacities

The microstructures of Mg_2Si magnesium matrix composites were determined by scanning electron microscopy (SEM, JSM−5610LV) equipped with energy dispersive X−ray spectrometer (EDS) operating at 20 kV. The dynamic mechanical analyzer (DMA, Q800, TA Instruments, USA) was used in the characterization of damping properties of spherical Mg_2Si magnesium matrix composites specimens under forced vibration by the test mode of single cantilever beam in this study. The damping capacities of spherical Mg_2Si magnesium matrix composites was measured by the method[8] of tangent phase angle φ expressed by $\tan\varphi$.

The measured specimens of prepared spherical Mg_2Si magnesium matrix composites were cut into the size of 10 mm×10 mm×10 mm for characterization of microstructures using SEM and 30 mm×10 mm×2 mm for determination of damping capacities using DMA by wire cutting electrical discharge machining (WEDM), and then ground with SiC abrasive paper in size of 800, 1600, and 2000 grits for successively polishing the surface of specimens, polished by silica suspension, and cleansed by distilled water and ethanol.

Two relationships have been studied between strain ε and internal friction $\tan\varphi$ of spherical Mg_2Si magnesium matrix composites specimens at ambient temperature, between temperature T and internal friction $\tan\varphi$ at constant strain ε. Then the damping properties of spherical Mg_2Si magnesium matrix composites specimen have been discussed.

The effect of strain ε from 1.0×10^{-3} to 1.0×10^{-1} on internal friction $\tan\varphi$ is determined at vibration frequency f =1.0 Hz. The influence of temperature T from ambient temperature T_{am} to 300 °C on internal friction $\tan\varphi$ is under conditions of the heating rate as 5 °C /min, and strain $\varepsilon=7.0\times10^{-2}$.

3 Experimental Results and Discussion

3.1 Microstructures of Mg_2Si magnesium matrix composite

The microstructure of the spherical Mg_2Si magnesium matrix composite prepared with 125 μm fly ash floating beads is shown in Figure 3.. It can be clearly observed that there are spherical phase and fragment-shaped phase in the matrix shown in blue circles. Due to effect of centrifugal force, the molten magnesium can be percolated into hollow space of fly ash floating beads with open pore structure in this study and formed spherical phase. However, some fly ash floating beads with lower strength and hardness were fragmented because of influence of centrifugal force and formed fragment-shaped phase.

Further EDS analysis was performed on the matrix region labeled A and the spherical region labeled B. The point EDS analysis result illustrates chemical compositions of region A are almost pure Mg phase containing traces of Al and O, and that of region B contains considerable Mg and Si with an atomic ratio of Mg:Si of approximately 2:1, which is confirmed as Mg_2Si phase.

Due to the fact that main composition of the fly ash floating beads is SiO_2, the reaction between Mg and SiO_2 at high temperatures can occur:

$$2Mg + SiO_2 \rightarrow 2MgO + Si \qquad (1)$$

Excess magnesium can continue to react with the generated Si and form Mg_2Si:

$$2Mg + Si \rightarrow Mg_2Si \qquad (2)$$

The formation of the Mg_2Si phase can be well explained by Eq. (1) and Eq. (2).

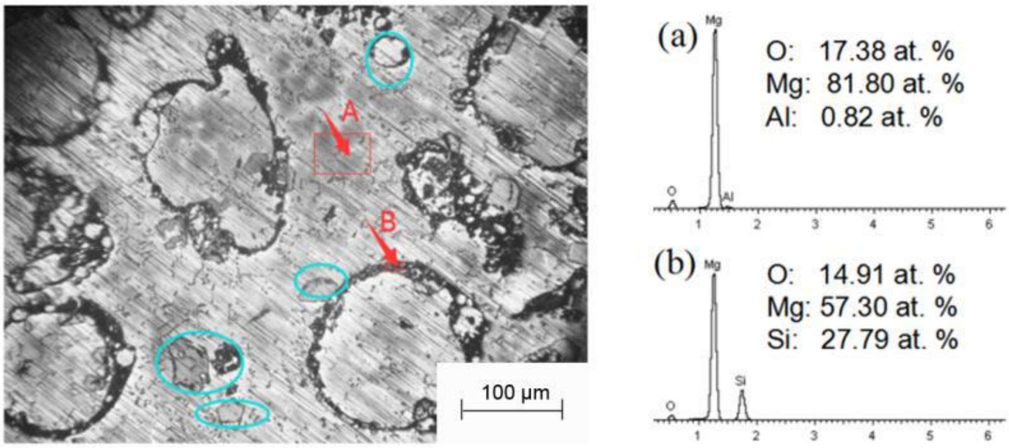

Figure 3. SEM micrograph of spherical Mg_2Si magnesium matrix composites and the corresponding point EDS spectra (a) area A, (b) area B

3.2 Damping Capacities of Mg_2Si magnesium matrix composites

The effect of strain ε from 1.0×10^{-3} to 1.0×10^{-1} on internal friction $\tan\varphi$ of Mg_2Si magnesium matrix composites prepared by 80, 125, and 500 μm fly ash floating beads under the condition of vibration frequency f =1.0 Hz shown in Figure 4. It can be evidently observed that damping capacities of three specimens have similar tendency with an increase of strain ε. This implies that the internal friction $\tan\varphi$ of three samples increase slowly with strain ε increasing in a range of 1.0×10^{-3} to 1.9×10^{-2}; however, the internal frictions $\tan\varphi$ exhibit a greatly increasing trend with an increase of strain ε from 1.9×10^{-2} to 1.0×10^{-1} and reach the maximum value of $\tan\varphi$ followed by a slight decline. Moreover, three specimens have higher damping capacities in the full strain range and reach the damping peaks in the vicinity of strain ε =5.2×10^{-2}, which can be attributed to the spherical structure of Mg_2Si in the matrix. It also can be observed that increasing particle size of fly ash floating beads can lead to an obviously decreasing tendency of internal friction $\tan\varphi$. It can be ascribed to the fact that the larger the particle size of fly ash floating beads with hollow structures, the less Mg_2Si phase formed resulting in lower dislocation density, less interface area and smaller damping value.

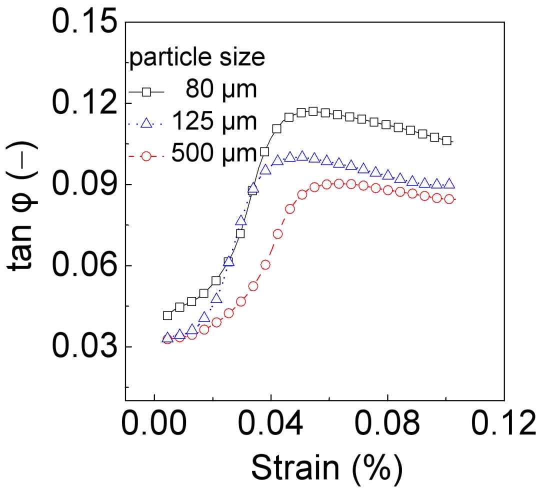

Figure 4. Effect of strain ε on damping capacities $\tan\varphi$ of spherical Mg_2Si magnesium matrix composites specimens at vibration frequency f =1.0 Hz

The influence of temperature T from ambient temperature to 300 °C on internal friction $\tan\varphi$ of Mg_2Si magnesium matrix composites prepared by 80, 125, and 500 μm fly ash floating beads under conditions of vibration frequency f =1.0 Hz and strain ε =7.0×10^{-2} is shown in Figure 5. It can be obviously observed that three specimens of magnesium matrix composites have higher damping capacities in whole temperature range especially $\tan\varphi$ =0.09 of the specimen with a particle size of 80 μm at T_{am}. In addition, the internal friction $\tan\varphi$ of three samples increase slowly with temperature T increasing from T_{am} to 150 °C; however, the internal frictions $\tan\varphi$ exhibit a greatly increasing trend with an increase of temperature T from 150 °C to 300 °C but no damping peaks occur. It also can be observed that increasing particle size of fly ash floating beads can lead to an obviously decreasing tendency of internal friction $\tan\varphi$ due to aforementioned reasons.

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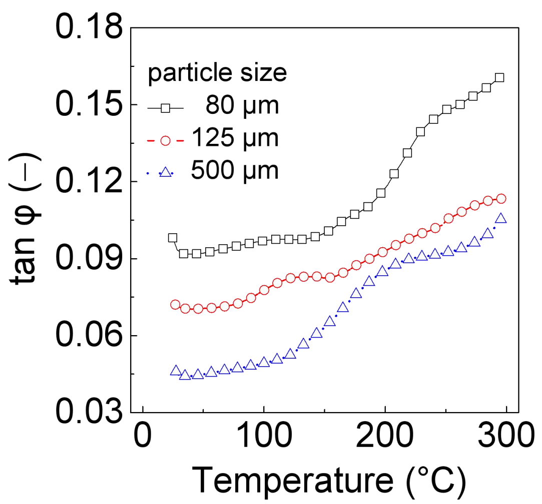

Figure 5. Effect of temperature T on damping capacities $\tan\varphi$ of spherical Mg_2Si magnesium matrix composites specimens at vibration frequency f =1.0 Hz and strain ε =7.0×10^{-2}

4 Conclusions

According to the experimental results of microstructure and damping capacities expressed by internal friction $\tan\varphi$ of spherical Mg_2Si magnesium matrix composite and related discussion, the main summary remarks can be obtained as follows:

(a) Spherical and fragment-shaped Mg_2Si phases were observed in the matrix, where fragment-shaped phases were formed owing to the reason that some fly ash floating beads with lower strength and hardness were fragmented because of influence of centrifugal force.

(b) Increasing particle size of fly ash floating beads can lead to an obviously decreasing tendency of internal friction $\tan\varphi$ ascribed to the fact that the larger the particle size of fly ash floating beads with hollow structures, the less Mg_2Si phase formed resulting in lower dislocation density,less interface area and smaller damping value.

(c) The critical strain ε_{cr} =1.9×10^{-2} of $\varepsilon-\tan\varphi$ curve and critical temperature T_{cr} =150 °C of $T-\tan\varphi$ curve for $\tan\varphi$ changing from slowly to greatly increasing. Damping peaks occur in the vicinity of strain ε =5.2×10^{-2} in $\varepsilon-\tan\varphi$ curve whereas no damping peaks occur in $T-\tan\varphi$ curve. Spherical Mg_2Si magnesium matrix composite have high damping capacities in the full strain and temperature range possibly ascribed to spherical structure of Mg_2Si in the matrix.

References

[1] B. L. Mordike and T. Ebert: Magnesium: Properties−application−potential. Mat. Sci. Eng. A, **302** (2001), pp. 37−45.

[2] J. Zhang, R. J. Perez and E. J. Lavernia: Effect of SiC and graphite particulates on the damping behavior of metal matrix composites. Acta. Metall. Mater., **42** (1994), pp. 395−409.

[3] J. Zhang, R. J. Perez: Dislocation-induced damping in metal matrix composites. J. Mater. Sci., **28** (1993), pp. 835−846.

[4] S. Narasirnalu, and G. Manoj: Damping characterization of Mg-SiC composites using an integrated suspended beam method and new circle-fit approach. Mater. Res. Bull., **37** (2002), pp. 1149−1162.

[5] W. Cao, C. F. Zhang, T. X. Fan, and D. Zhang: In situ synthesis and damping capacities of TiC reinforced magnesium matrix composites. Mater. Sci. Eng. A, **496** (2008), pp.242−246.

[6] L. H. Liao, H. W. Wang, X. F. Li, and N. H. Ma: Research on the dislocation damping of Mg_2Si/Mg−9Al composite materials. Mater. Lett., **61** (2007), pp. 2518−2522.

[7] Z. Wang, J. T. Gao, K. Chang, L. Meng, N. Zhang and Z. C. Guo. He: Manufacturing of open-cell aluminum foams via infiltration casting in super-gravity fields and mechanical properties. RSC. Adv., **8** (2018), pp. 15933−15939.

[8] R. L. Niu, F. J. Yan, Y. S. Wang, D. P. Duan, and X. M. Yang: Effect of Zr content on damping property of Mg−Zr binary alloys. Mater. Sci. Eng. A, **718** (2018), pp. 418–426.