

## Effect of particle clustering on fatigue behavior of Mg-amorphous alloy composite

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### ABSTRACT

In this paper, fatigue tests were conducted on the new class of magnesium matrix composite reinforced with amorphous alloy particle. Effect of microstructure and particle distribution on fatigue properties is investigated. The difference of the microstructure is the cause for different crack initiation and propagation and this condition influenced fatigue life. In this study, a new method is extended for the characterization of particle local volume fraction variation by including area-probe based averaging. The heterogeneity of the particle spatial distribution is characterized from the fractured surface of the specimens. The results of this study shows the spatial distribution of reinforcements is one of the fundamental microstructural quantities and correlates with mechanical properties of particulate reinforced composites, such as fatigue properties. The distribution of reinforcement particles controls the extrusion load. In the case of non-uniform particles distribution, there are several fracture origins and these conditions influenced fatigue life of the material. The specimens extruded at higher load have higher fatigue life.

### 1 Introduction

New lightweight composites are needed to improve the energy efficiency of engineering structural materials, in different industries. Further development of the new advanced composite structures requires the utilization of new materials and advanced production technology. In this development work, microstructural characterization of composite materials is a necessity for understanding the relationships between microstructural quantities and mechanical properties. Mechanical properties of particulate reinforced composites are highly dependent on the real microstructure of the composite, particle distribution and volume fraction [1-5]. In this respect, methods capable of measuring the local volume fraction and particle distribution in particulate reinforced composites are most desirable. These measures can be used e.g. for quality control of a composite material, and tuning of processing parameters.

Amorphous alloys/bulk metallic glasses (BMG) are novel metallic materials which are different from conventional crystalline metals/alloys. They exhibit superior properties such as extremely high strength (1 to 2 GPa), large elastic strain limit of ~2% and superior corrosion resistance, etc. [6-7]. Recently, there have been some attempts to use the metallic glass particles as reinforcement in metal matrix composites [8-11]. In this study, Ni<sub>60</sub>Nb<sub>40</sub> mechanically alloyed amorphous powders were used to reinforce pure Mg metal, to produce Mg-amorphous alloy composite. In automotive and aerospace industries, composites should sustain mechanical loading. Thus, special distribution of reinforcements as one of the fundamental microstructural quantities is investigated on fatigue strength of amorphous particulate reinforced composites as a new class of lightweight composite materials prior to their application in industries.

## 2 Experimental details

### 2.1. Material

The material sample preparation has been explained in Ref. [12]. Since the composites are fabricated by a powder metallurgy and extrusion process, it is often difficult to obtain a uniform and homogeneous distribution of reinforcement particles practically. The results of tensile testing and microstructural characterization clearly reveal that the distribution of reinforcement particles controls the extrusion load [12]. Fig.1a-b show the microstructures of 3 vol. %  $\text{Ni}_{60}\text{Nb}_{40}/\text{Mg}$  composites chosen from different billets extruded at 650 and 550 psi, respectively. Fig.1c-d shows the microstructure of 5 vol. %  $\text{Ni}_{60}\text{Nb}_{40}/\text{Mg}$  composites chosen from various billets extruded at 750 and 600 psi, respectively.

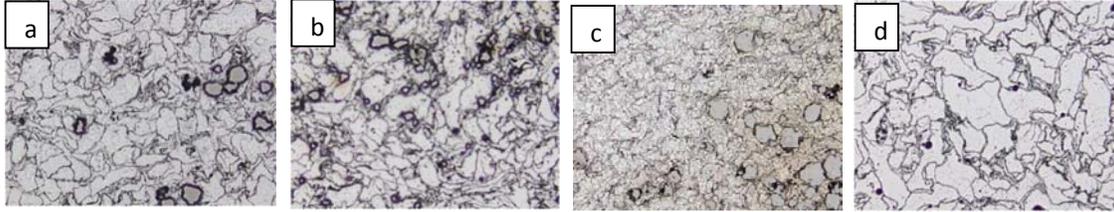


Figure 1: Microstructure of composites: (a) 650 psi, (b) 550 psi, and (c) 750 psi, (d) 600 psi.

### 2.2. Specimens

For high cycle fatigue testing, hour-glass shaped round specimens were used; the dimensions of the specimens are shown in Fig. 2.

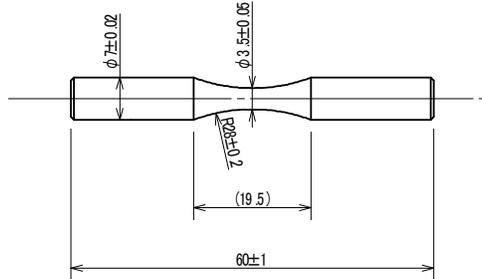


Figure 2: Configuration of fatigue specimen.

## 3 Results and discussion

Fatigue testing is done for 3 vol. % and 5 vol. % composite with different extrusion load at stress amplitude 70 MPa and 90 MPa, respectively. Figure 3a-6a shows fracture surface observations of the specimens with different particles distribution for 3 and 5 vol. % composite, respectively. The results of fatigue failure are listed in Table 1. It is evident that specimens with more uniform particle distribution possesses a superior fatigue strength.

Material		$N_f$
<b>3 Vol. %</b>	650 psi	$2.12 \times 10^4$
	550 psi	$1.01 \times 10^4$
<b>5 Vol. %</b>	750 psi	$1.17 \times 10^4$
	600 psi	$2.01 \times 10^2$

Table 1: Results of t fatigue testing.

In this study, the local volume fraction of particles have been measured using line-probe averaging previously used for the characterization of grain size distribution in welded structural steel [13-14]. In this investigation, the method is extended for the characterization of particle local volume fraction variation by including area-probe based averaging. The heterogeneity of the particle spatial distribution is characterized from the fractured surface of the specimens.

Moreover, the local volume fraction variation and clustering of particles have been investigated by defining the local area based averaging. Figures 3b-4b show the variation of particle volume fraction over the fractured surfaces of 3 vol. % Ni<sub>60</sub>Nb<sub>40</sub>/Mg composites chosen from different billets extruded at 550 and 650 psi using horizontal and vertical line probes. The width of the rectangular probe moved across the images is 300 μm. In these figures, the local volume fraction variation and clustering of particles have depicted simultaneously using the local area-based averaging, with the area probe size 300×300 μm rectangle.

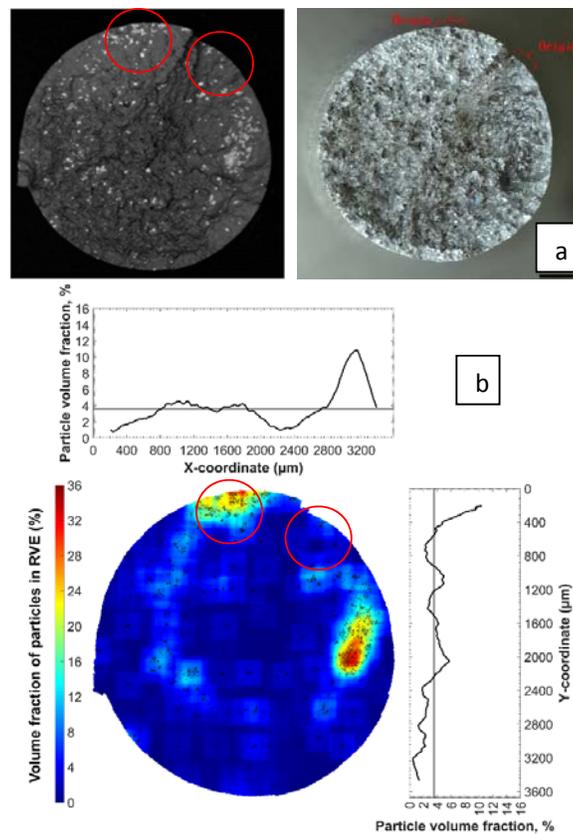


Figure 3: 3 vol. % composite extruded at 550 psi: (a) fracture surface observations (b) The variation of volume fraction and local clustering of particles over the fractured surface.

In Fig 3b, the clustering of particles on the top and right side of the fractured surface is visible from the moving averages, while in Fig 4b, the variance around the mean particle volume fraction is quite small. The same analyses have been done over the fractured surfaces of 5 vol. % Ni<sub>60</sub>Nb<sub>40</sub>/Mg composites chosen from different billets extruded at 600 and 7500 psi, respectively, as shown in Figures 5-6.

From the visualizations of local area-based averaging over the fractured surface, it can be seen that some local regions have a higher concentration of particles than the average volume fraction in the material. It is evident that differences between local and mean volume fractions are higher in the case of non-uniform particle distribution. Based on fracture surface analyses, it seems that the crack initiation happens at the location where there is a large particle gradient: highly clustered areas or the surrounding material near a clustered area.

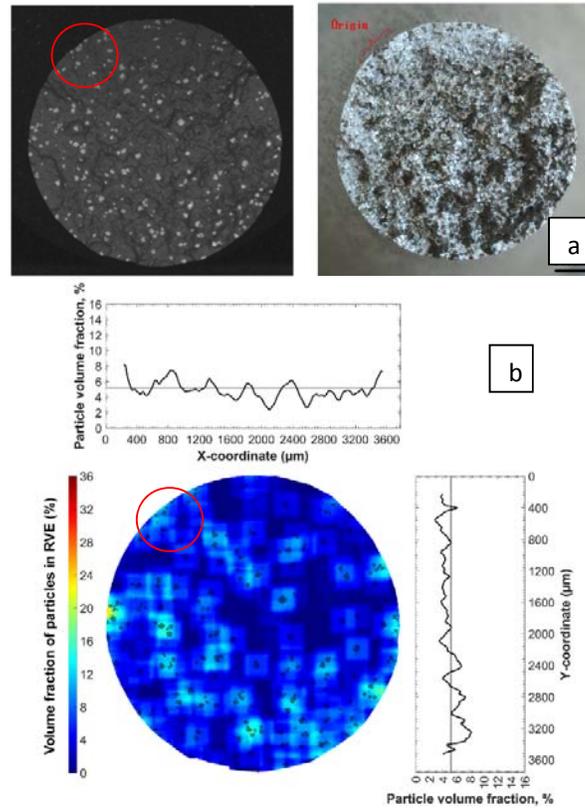


Figure 4: 3 vol. % composite extruded at 650 psi: (a) fracture surface observations (b) The variation of volume fraction and local clustering of particles over the fractured surface.

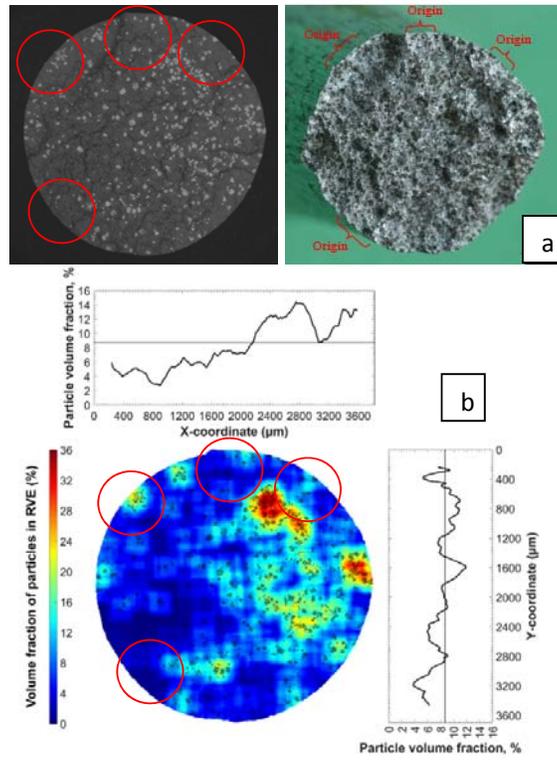


Figure 5: 5 vol. % composite extruded at 600 psi: (a) fracture surface observations (b) The variation of volume fraction and local clustering of particles over the fractured surface.

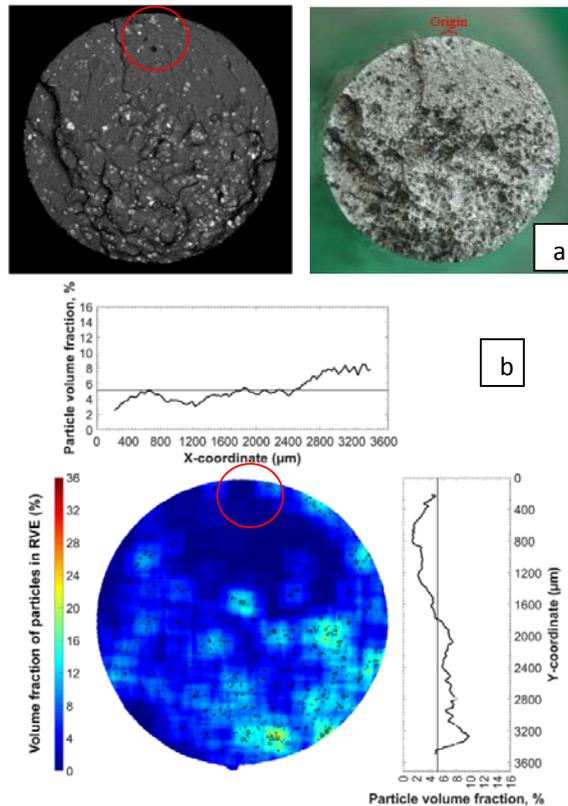


Figure 6: 5 vol. % composite extruded at 750 psi: (a) fracture surface observations (b) The variation of volume fraction and local clustering of particles over the fractured surface.

#### 4 Conclusion

The results of this study shows the spatial distribution of reinforcements is one of the fundamental microstructural quantities and correlates with mechanical properties of particulate reinforced composites, such as fatigue properties. The distribution of reinforcement particles controls the extrusion load. In the case of non-uniform particles distribution, there are several fracture origins and these conditions influenced fatigue life of the material. The specimens extruded at higher load have higher fatigue life.

This kind of information enables one to discriminate quantitatively the difference of the same kind of materials manufactured by different methods. Thus, this information will be useful for the quality control of materials and the improvement of manufacturing process.

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