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Fatigue crack growth behavior of amorphous particulate reinforced composites

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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. The high cycle fatigue behavior and the ability to resist crack nucleation and propagation of $Ni_{60}Nb_{40}$/Mg composites have been studied. Moreover, effects of microstructure and particle distribution on fatigue properties and crack growth mechanism are investigated. The difference of the microstructure is the cause for different crack initiation and propagation and this condition influenced fatigue life. Composites with more uniform particle distribution possess a superior fatigue resistance in fatigue limit. *In situ* crack growth observation revealed fatigue crack initiation occurred preferentially at particle-matrix interfaces. In addition, it was observed that the crack growth in particulate reinforced composites is highly localized phenomenon, influenced primarily by the distribution and microstructure of particles near the vicinity of the crack tip. The crack propagation through the matrix and region of well-dispersed particles is predicted by a crack growth law while crack propagation through the region of particle clusters is considerably different and unpredictable.

1. Introduction

Magnesium is actively used as a lightweight metal in the aerospace and automotive industries. In recent years, these industries are investing in great deal into the research and development of light weight, energy efficient magnesium based materials [1–4]. Magnesium also possess notable properties such as excellent damping capacity, castability, machinability, and low temperature processing advantages which makes it suitable for a spectrum of engineering applications [5]. However, the relatively low elastic modulus, low strength and poor high temperature stability limit the range of magnesium applications [6]. Literature study reveals that most of these limitations can be improved through the incorporation of alloying elements and/or reinforcements.

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 (1–2 GPa), large elastic strain limit of ~2% and superior corrosion resistance, etc. [7,8]. Looking at the unique properties of the amorphous alloys/BMG, it is advantageous to use them as reinforcements for making light metal composites. Recently, there have been some attempts to use the metallic glass particles as reinforcement in metal matrix composites [9–15].

This new class of composites, as a structural material, especially in automotive and aerospace industries should sustain mechanical loading. Thus, the resistance of amorphous particulate reinforced composites to fatigue crack growth must be explored prior to their application in automotive and aeronautic industries. A detailed understanding of fatigue failure processes is, therefore, of considerable interest to reliably predict and optimise the fatigue resistance of these materials. The high cycle fatigue properties and crack propagation mechanism of Mg-amorphous alloy composite have not yet been clarified in details. In this study, $Ni_{60}Nb_{40}$ mechanically alloyed amorphous powders were used to reinforce pure Mg metal, to produce Mg-amorphous alloy composite. Fatigue tests were conducted on $Ni_{60}Nb_{40}$/Mg composites with different particle volume fractions to investigate fatigue lives (S–N curves) and crack propagation behavior. Moreover, this paper investigates the effect of particle distribution and morphology on fatigue behavior and crack growth process of particulate reinforced composites.

2. Experimental details

2.1. Material

Amorphous alloy powder with composition $Ni_{60}Nb_{40}$ (at.%) was prepared by mechanically alloying powder mixtures of elemental Ni and Nb metals. The powder mixture was milled at room

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temperature in air for 87 h, using a Retsch PM400 planetary ball mill with a ball-to-powder ratio of 3:1 and milling speed of 200 rpm. To produce Mg-composites, elemental Mg-powder (99.6% purity) was blended with varying volume fractions (3% and 5%) of $Ni_{60}Nb_{40}$ powder for a duration of 1 h and consolidated at room temperature at 450 MPa for 1 min. The compacted cylindrical billets of 36 mm diameter were microwave sintered at 100% power level for 12.30 min so as to achieve a temperature of 550 °C (based on prior calibration). The sintered billets were soaked at 400 °C for 1 h, and hot extruded at 350 °C to produce rods of 8 mm diameter. The extruded rods were used for further testing.

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 [16]. Fig. 1a and b shows the microstructures of 5 vol.% $Ni_{60}Nb_{40}$/Mg composites chosen from different billets extruded at 750 and 600 psi, respectively. Fig. 1c and d shows the microstructure of 3 vol.% $Ni_{60}Nb_{40}$/Mg composites chosen from various billets extruded at 650 and 550 psi, respectively. The material properties of the composite constituents are presented in Table 1.

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. After machining, a layer with thickness of about 100 μm was removed from the surface of the specimens by electrolytically polishing in order to avoid the influence of machining on the fatigue results.

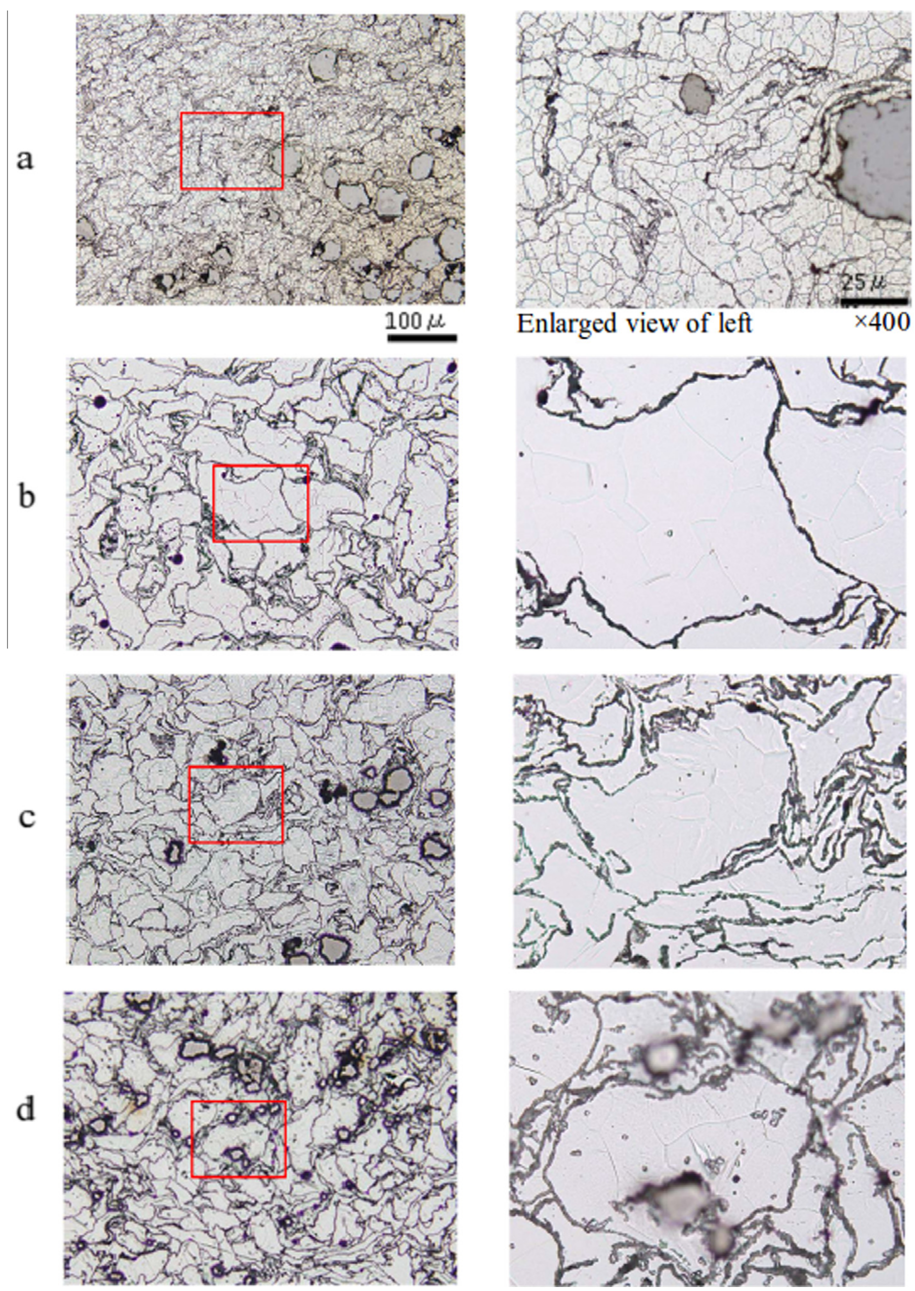

Fig. 1. Microstructure of composites: (a) 5 vol.% composite 750 psi, (b) 600 psi, and (c) 3 vol.% composite 650 psi, (d) 3 vol.% composite 550 psi.