Strain-rate Sensitivity of Aluminum 2024-T6/TiB₂ Composites and Aluminum 2024-T6

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Abstract: Strain-rate sensitivities of 55vol%-65vol% aluminum 2024-T6/TiB₂ composites and the corresponding aluminum 2024-T6 matrix were investigated using split Hopkinson pressure bar method. The experimental results showed that 55vol%-65vol% aluminum 2024-T6/TiB₂ composites exhibited significant strain-rate sensitivities, which were three times higher than the strain-rate sensitivity of the aluminum 2024-T6 matrix. The strain-rate sensitivity of the aluminum 2024-T6 matrix composites rose obviously with increasing reinforcement content (up to 60%), which agreed with that from the previous researches. But it decreased as the ceramic reinforcement content reached 65%. After high strain rates compression, a large number of dislocations and micro-cracks were found inside the matrix and the TiB₂ particles, respectively. These micro-cracks can accelerate the brittle fracture of the composites. The aluminum 2024-T6/TiB₂ composites showed various fracture characteristics and shear instability was the predominant failure mechanism under dynamic loading.

Key words: composite materials; mechanical properties; dynamic compression; strain-rate sensitivity

1 Introduction

Particles reinforced metal matrix composites (PRMMCs) have attracted more attention in aerospace and automobile industries. As the reinforcement volume content of composite material is more than fifty percent, a high specific modulus and specific strength as well as a low coefficient of thermal expansion can be obtained. These excellent properties have made them ideal candidate materials for electronic packaging components and armor structures[1,2]. These functional material structures may be subjected to collisions inevitably.

The dynamic mechanical response of aluminum matrix composites, typically with low reinforcement volume content, has been well developed by several researchers, also with theoretical models for such response constructed[3-7]. However, fewer investigations have been conducted on the high reinforcement content composites. In the present work, the dynamic response of composites containing more than 50vol% reinforcement particles is explored. Due to the higher hardness, elastic modulus and higher chemical stability of TiB₂ ceramic relative to the common ceramic particles such as SiC and Al₂O₃, recently aluminum 2024/TiB₂ composites have been developed extensively for structural materials applications. The present study is concentrated on the aluminum 2024-T6/TiB₂ composites (Vₚ=55%-65%) fabricated by pressure infiltration method. The strain rates sensitivities of these composite materials at strain rates of 1×10⁴-2×10⁵ s⁻¹ were investigated.

2 Experimental

In the present work, TiB₂ ceramic particles with an average size of 8 μm were chosen for the reinforcement. An Al-Cu-Mg alloy (2024Al) was selected as the matrix. The composites, with TiB₂ particles content in the range of 55vol%-65vol%,...
were produced by pressure infiltration method. T6 heat treatment was performed on aluminum 2024-T6/TiB$_2$ composites. This involved a solid solution treatment at 768 K for 1 h followed by aging treatment at 433 K for 10 h. A conventional split Hopkinson pressure bar (SHPB) was used to obtain high strain rate compression response of the materials over a strain rate range of $1 \times 10^3$-$2 \times 10^3$ s$^{-1}$. Cylindrical test specimens with a length of 8 mm and a diameter of 8 mm were cut from the composites using electro-discharge machining. In order to compare with high strain rate response, the quasi-static compression tests were conducted on Instron machine with a constant cross-head speed of 0.5 mm/min. The diameter of the quasi-static compression specimen was 8 mm and the length was 12 mm. All tests were performed at room temperature with sufficient lubrication to prevent barreling in the specimens. Microstructures of the composites were examined by S-570 scanning electron microscopy (SEM). Density and hardness as well as Young’s modulus of the composites were measured, the mechanical properties of the composites are revealed in Table 1.

### 3 Results

#### 3.1 Dynamic stress-strain curves

Fig.1 gives the dynamic compression stress-strain curves of 55vol%-65vol% aluminum 2024-T6/TiB$_2$ composites and the corresponding aluminum 2024-T6 matrix. The 60vol% aluminum 2024-T6/TiB$_2$ composite gets the highest flow stresses at high strain rates among the three composites, which is similar to those under quasistatic loading, revealed in Fig.1(a). Moreover, it can be found that aluminum 2024-T6/TiB$_2$ composites show significant strain-rate strengthening characteristics at high strain rates, while the strain hardening is the primary strengthening mechanism for aluminum 2024-T6 alloy, as revealed in Fig.1(b). The aluminum 2024-T6 alloy, similar to those reinforced with low content reinforcement (about 25vol%), shows significant insensitivity to strain rates. The difference in strain rate sensitivity between 55vol%-65vol% aluminum 2024-T6/TiB$_2$ composites and the aluminum alloy matrix would be related to the high reinforcement content.

In the present work, the dynamic compression stress-strain curves of the aluminum 2024-T6/TiB$_2$ composites show rise/drop tendency with increasing strain. Additionally, 55vol% and 60vol% aluminum 2024-T6/TiB$_2$ composites exhibit the larger elongation at high strain rates than those under quasistatic loading. We consider that the large elongation and the flow stress softening are caused by adiabatic temperature rise, which is transferred by plastic deformation work during adiabatic compression. The average adiabatic temperature rise within the MMC can be calculated as follows:

$$
\Delta T = \int_0^{\varepsilon_f} \frac{\beta \sigma}{\rho C_m} \, d\varepsilon
$$

where, $\beta$ is the fraction of the plastic work converted into heat, for example, a value of 0.9 for aluminum