Experiment research on the dynamic mechanical behavior of aluminum matrix syntactic foam

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The dynamic mechanical behavior of aluminum matrix syntactic foam in the strain rate range from $1700s^{-1}$ to $3800s^{-1}$ was investigated by Hopkinson pressure bar system. Compared to the mechanical behavior under quasi-static loading, syntactic foam showed higher strength under dynamic loading. But the significant distinguish of strain rate can't lead to the obvious difference of strength. On the other side, the aluminum matrix syntactic foam exhibited excellent energy absorption efficiency. The value of energy absorption efficiency exceeded 0.7 under dynamic loading, even more it reached 0.9 at $2700s^{-1}$. These results indicated aluminum matrix syntactic foam was suit for energy absorption application under impact loading.

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1. Introduction

Metal foam within pores could be used widely in the field of damping and impact absorption, because they have ability to suffer large plastic strains at a nearly constant stress level. In the past, metal foam was a novel functional material with advance properties; therefore it attracts much attention of researchers. Along with the development of metal foam fabrication, the quasi-static mechanical behavior of metal foams fabricated by different crafts was investigated overall [1-4]. These researches showed the mechanical behavior and its influencing factor under quasi-static loading. However, McCullough and Mukai [5-6] reported there are huge difference of mechanical properties and deformation in aluminum foam between quasi-static loading and dynamic loading. Under impact loading, the deformation mechanism and the relationship between stress and strain would visibly alter by the strain rate. It is the famous "strain rate effect" [7-10]. In addition, most of researchers recognized that the strain rate effect in metal foams is caused by the difference of microstructure [11-13].

The compressive strength of aluminum matrix syntactic foam is higher than aluminum foam; therefore it is suitable to apply in complex surrounding. However, today there are less research on the aluminum matrix syntactic foam due to the difficult of fabrication and the lack of research method. Most of researches focused on the quasi-static mechanical behavior, rare researches were on the dynamic mechanical behavior [14-17]. The dynamic mechanical behavior of high-strength aluminum alloy aluminum matrix syntactic foam is of special interest. In this paper, the main object was to study the high strain rate compression behavior of aluminum matrix syntactic foam.

2. Materials and experiment

2.1 Materials

In this paper syntactic foam was fabricated by pressure infiltration technique, described in detail elsewhere [18]. The matrix of composite was pure aluminum. The cenospheres, which had average diameters of 200μm, were extracted from the original fly ash waste to serve as fillers. The microstructure of aluminum matrix syntactic foam is shown in Fig. 1. Additionally, the porosity ratio of cenospheres in the syntactic foams was about 45%.

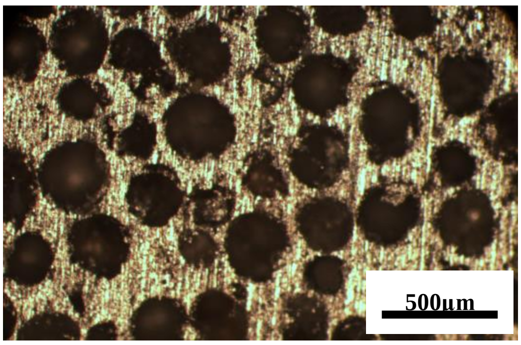

Fig. 1. Microstructure of aluminum matrix syntactic foam.

2.2 Dynamic compression tests

Dynamic compression tests were performed on Split Hopkinson Pressure Bar (SHPB) apparatus, as given in Fig. 2. A typical SHPB system consists of two slender compression bars, a short impact bar, strain gauges and equipment for recording the stress wave. The diameters of the incident bar and transmission bar are both 12.7mm, and the length of the incident bar and transmission bar are both 1000mm. In this paper, the incident and transmission bars were made of 7075 aluminum alloys when the syntactic foam was examined. The samples in dynamic compressive test were φ7×3mm.

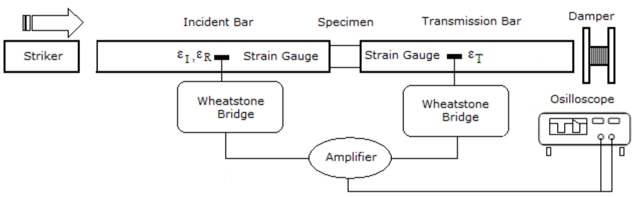

Fig. 2. Schematic diagram of SHPB system.

Above all tests were accomplished at room temperature, and three samples were repeatedly tested at least on every compressive condition.

3. Results and discussion

The dynamic mechanical behavior of aluminum matrix syntactic foam was investigated in the strain rate range of $1700s^{-1}$~$3800s^{-1}$. Fig. 3 shows a representative set of incident and transmitter signal collected in SHPB test at $3800s^{-1}$. The first pulse is from the incident wave when stress wave went through the incident bar. After the incident stage, the stress wave arrived at the surface of syntactic foam. Consequently, one part of the stress wave passed into the transmission bar, this part of stress wave is recorded as the transmitted pulse. The rest of the incident stress wave were reflected in incident bar and recorded as the reflected pulse. The stress-strain curves, strain rate curves are all calculated by the three pulses (incident pulse, transmitted pulse and reflected pulse) with a specific method.

Fig. 4 shows the strain rate curves of syntactic foam, which is calculated by the pulse collected in the SHPB tests. Three strain rate curves are consisted of three stages, which is similar as the stress-strain curve of cellular materials. At the beginning of compression, the strain rate increases dramatically and reaches a peak. Unfortunately, the peak value appears quickly because of the crush of cenospheres in syntactic foam. Consequently, strain rate reduced a little and turn into a stable stage. Finally, the strain rate decays gradually corresponding to the third stage. In the third stage, after densification strain the syntactic foam changes gradually farctate due to the crush of cenospheres. Hence, the strain rate decreases gradually.

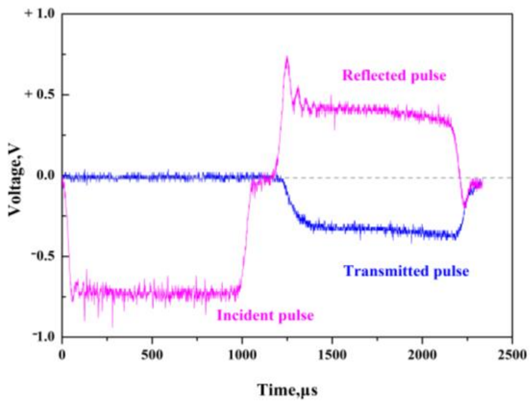

Fig. 3. Stress wave collected by oscillometer in the dynamic compression test at $3800s^{-1}$.

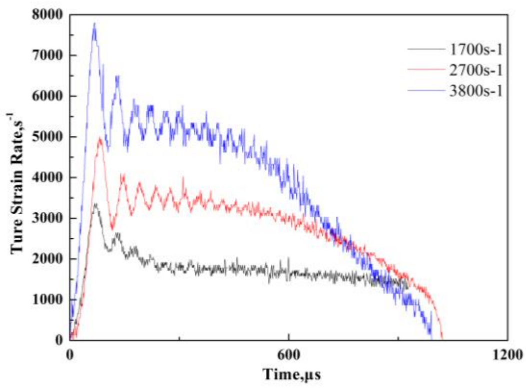

Fig. 4. Strain rate in dynamic compression test.

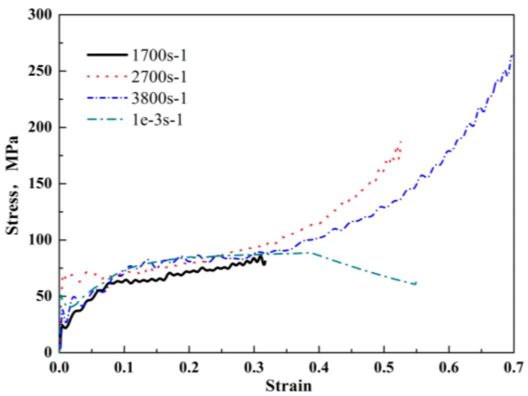

Fig. 5. Mechanical response of syntactic foams.

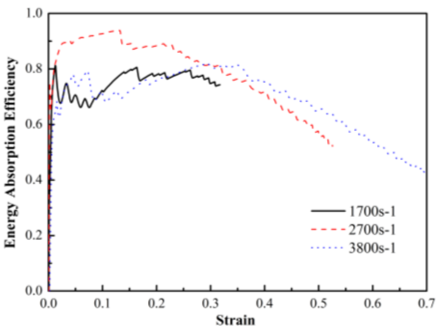

Fig. 6. Energy absorption efficiency under dynamic loading.

Fig. 5 describes the stress-strain curves of syntactic foams in the strain rate range of $1700s^{-1}$~$3800s^{-1}$. In addition, one curve under quasi-static is presented to compare with dynamic compress. The compressive strength under dynamic loading is higher than that under quasi-static loading. However the compressive strength at different strain rate under dynamic loading doesn't exhibit obvious discrimination. The result is similar as the investigation of Dou [19]. The micro-inertia effects of aluminum foam come from the strain rate effect of matrix aluminum and the gas flow inside the cell. However, there may be other potential reasons (i.e. the micro-inertia effects) for rate sensitivity of the syntactic foams. In the other paper, this problem is discussed.

The energy absorption efficiency is an important parameter to evaluate the energy absorption. It could be calculated by the equation below:

$$\eta = \frac{\int_0^{\varepsilon} \sigma d\varepsilon}{\sigma_{max}\varepsilon} \quad (1)$$

Where, σ is the stress at a given strain, ε is the strain rate, σ_{max} is the maximum stress, ε_D is the densification strain.

The results are showed in Fig. 6. The energy absorption efficiency of syntactic foams exceed 0.7 under dynamic loading, which is similar as most of cellular materials. Even it could reach 0.9 at the strain rate of $2700s^{-1}$. The results indicate syntactic foam is suit for energy absorption application.

4. Conclusions

SHPB tests were carried out to assess the dynamic mechanical behavior of aluminum matrix syntactic foam. The results indicate that, the compressive strength under dynamic loading is higher than that under quasi-static loading. However the compressive strength at different strain rate hasn't distinguished obviously, under dynamic loading.

The energy absorption efficiency of syntactic foams exceeds 0.7 under dynamic loading, which indicates syntactic foam is suit for energy absorption application.

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