Fatigue Shear-band in Metallic Glass

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Metallic glass (MG) is a class of metallic material fabricated by the fast-cooling during solidification. This alloy lacks the long-range order characteristic and the crystalline defects including grain boundaries and dislocations. The unique structural feature makes some mechanical properties of MG obviously superior than conventional crystalline alloys, such as strength, hardness, elastic limit, wear resistance, etc. It is estimated that ~90% of all mechanical failures in the structural materials are caused by fatigue. Thus, the fatigue property is an important evaluation index before a new structural material application. Without the dislocations and grain boundaries, the plastic deformation of MG occurs in the form of atomic clusters operation at room temperature, eventually leading to the generation of shear band. It is found that the fatigue damage and fracture of MGs were dominated by shear band. As a result, understanding how shear band evolution under cyclic loading is important for improving the fatigue performance of MGs.

metallic glass | shear band | fatigue property | fatigue crack | free volume

1. Introduction

Metallic glass (MG) usually shows extremely high strength, high elastic strain, high hardness, and sometimes high toughness, which make this class of material attractive for structural applications [1][2][3]. However, the fatigue property of MGs are not so promising[4]. The fatigue mechanism of MG was investigated based on the fatigue damage observations on the sample surface and fractography analyses. Similar to crystalline metals, the casting or processing defects usually exist in the fatigue crack initiation region of MG. Due to the large stress concentration near the defects, the fatigue crack preferentially forms from the defects. However, some studies reported no defects observed after fatigue fracture [5][6], implying another fatigue crack initiation mechanism. As such, the shear band is considered to be responsible for the fatigue cracking mechanism of MG, just like the slip band mechanism in crystalline metals.

2. Shear Band-Mediated Fatigue Cracking Mechanism

Wang et al. [7] designed the quasi-in situ compression tests under cyclic loading with the maximum stress lower than the yield strength and captured the shear band evolution process by SEM observation. It is found that the shear band emerged from the specimen edge before the fatigue crack formation, confirming the shear band formation under cyclic stress lower than the yield strength. With increasing the fatigue cycles, fatigue crack seems to initiate from the onset of shear band, and some microcracks emerge inside the shear band ahead of fatigue crack tip. After long cycles, the main fatigue crack becomes wider and longer, and some secondary cracks were also generated. Eventually, the fatigue fracture occurs along the main shear band in a shear mode. These results well demonstrate the shear band-mediated fatigue cracking mechanism of MG.

For the shear band propagation, there are many studies under monotonic loading. For instance, Qu et al. [8] measured the shear offsets in different positions of shear band by using surface scratches as "rulers" and proved the existence of progressive propagation mode of shear band in monotonic compression. Under cyclic loading, Wang et al. [9] found shear bands with maximum local shear offset of several micrometers but without transecting the sample, suggesting the shear band progressively grows under cyclic compression. The local shear offset distributes linearly in the shear bands, and with increasing fatigue cycles, the local shear offset increases while the slope keeps unchanged. During the progressive propagation of shear band under monotonic loading, the applied stress increases with increasing the strain, indicating the apparent “work-hardening” behavior [8]. In contrast, applying the identical cyclic stress level can also induce the progressive propagation of shear bands, which indicates that the “plastic softening” occurs under cyclic loading in MG. This phenomenon is explained by the effect of cyclic loading on microstructural change.

Controlling the shear banding behavior should be an effective way to enhance the fatigue property of MG. Indeed, in this view, several extrinsic methods such as coating, shot peening etc. have been applied to enhance the fatigue property [10][11]. More importantly, there are two intrinsic methods of enhancing the fatigue property of MG. One is to proliferate the shear bands after fatigue crack initiation and then to prevent the fatigue crack propagation, as been verified in high-toughness MGs [5][12]. On the other hand, Wang et al. [13] proposed a new strategy by properly tailoring the microstructure to increase the resistance to shear band formation and then preventing the fatigue crack initiation from the shear band. This new strategy can be verified by two applications: (1) annealing treatment [13] and (2) processing condition control [14].

Firstly, she annealing treatment can relax the microstructure and suppress the formation of the shear band. The annealing is also controllable, nondestructive and easy to conduct in practice. To determine better microstructure of MG with enhanced fatigue property, the results of simple mechanical tests including uniaxial tension, compression and notch tension can be used as feedbacks. The treated MG with improved elastic limit but only slightly decreased notch toughness than the as-cast sample was proved to show enhanced fatigue property. The enhanced elastic limit implies the improved resistances for shear band formation and thus fatigue crack initiation, while the still high notch toughness guarantees the large tolerance for fatigue failure [13].

Secondly, the processing conditions such as the casting temperature and cooling rate can largely affect the microstructure of MG, eventually inducing different shear-band behaviors and mechanical properties. By examining the thermal properties and fatigue properties of two batches of MGs with different processing conditions but the same composition, Wang et al. [14] found the MG with the lower free volume level shows better fatigue property and suppressed shear banding behavior.

The large difference among the fatigue property of MG is caused by many external factors including materials quality, loading mode, stress ratio, specimen geometry, residual stress and so on. Investigating the correlation between these factors and shear banding behaviors is a viable approach to further clarify the fatigue mechanism and property [4].

This Entry is edited based on Refence [4].

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