Adiabatic Shear Localization in Ultrafine-grained Metals

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Abstract. Adiabatic shear localization (ASL) is a critical failure mode under impact loading for metals, especially for Ultrafine-grained/ nanocrystalline (UFG/NC) metals. In this work, the adiabatic shear failure behavior of UFG titanium was investigated by dynamic compression tests on hat-shape specimens combined with high-speed photography and infrared temperature measurement system. The mechanical response, temperature rise and deformation process including adiabatic shear band (ASB) initiation and crack formation was synchronously recorded by experiments. Essential characteristics of ASB, such as width, temperature, critical strain and propagation speed were carefully studied. The ASB of CG titanium was also studied for comparison. The results indicate that UFG appears good deformation ability than tensile tests and the critical strain for ASB initiation of UFG titanium is about 0.37, whereas it is about 0.69 for CG counterparts. The propagation velocity of ASB is dependent on the impact velocity and the maximum velocity in this work is 500-800m/s. The maximum temperature within ASB is in the range of 300-700℃, while the material close to ASB is also heated.

Introduction

UFG (grain size d between 100 to 500nm) and NC (grain size d<100nm) materials have drawn extensive attention in the last few decades due to their superior mechanical properties, such as improved yield stress, high strength and good wear resistance[1]. However, one fatal drawback that hinders their engineering application is the decreased ductility. Many researchers have focused on this manner and made their contributions[2, 3]. The failure of UFG/NC metals under tension usually starts from necking while under compression from shear banding. As in the case of dynamic loading, ASL is recognised as a trigger of catastrophic failure for most UFG/NC metals[4, 5]. ASL is one of the failure mechanisms those are commonly observed within ductile materials under dynamic loading. ASL process is always accompanied with the formation of ASB and followed by the final fracture of the material. However, the shear localization behaviour of UFG/NC materials under impact loading was not extensively investigated and the only few works were mainly on body centred cubic(BCC) metals[6, 7]. Previously, we examined the ASL behavior of CG titanium[8, 9].In this work, we will investigate the shear localization behavior of a commercially pure titanium with UFG structure by Kolsky bar system combined with high-speed camera and infrared(IR) temperature measurement system.

Experimental techniques

Commercial purity UFG titanium (TA2) was prepared by equal channel angular pressing (ECAP) technology with 4-pass B_C route . The composition of the material was given in Table 1.

Table 1 The composition of commercial purity titanium (TA2)

element	O	Fe	N	C	H	Ti
content	≤ 0.25	≤ 0.30	≤ 0.05	≤ 0.10	≤ 0.015	Bal

Plat hat-shape specimens were adopted to complete those experiments in this work, and figure 1 shows the schematic of the specimen. For all the investigations, the width of hat, width of hole, hight of shear region, thickness of specimen were chosen to be: $W1$=2.60 mm, $W2$=2.53 mm, h=1.00 mm, t=4.50 mm respectively. Line patterns with spacing of 0.16mm were engraved on some of the specimen surface to get clear observation of the deformation process. In order to study the shear mechanical properties of UFG Pure titanium, the quasi-static and dynamic testing were independently performed in MTS and split Hopkinson bar (Kolsky bar) system. The diameters of the bars were 12.7mm. The length of striker is 200 mm, the stress pulse width is about 80μm, and the velocity of striker is about 13 m/s.By using an 8-channel array InSb high speed infrared temperature measuring system, the adiabatic shear temperature rise of UFG pure titanium can be measured directly, and the variation of temperature will be studied in the process of deformation. Besides, an up to 5 million-frame resolution high-speed camera was used to record the real-time deformation of sample. The experiment technique mentioned above constitutes the experimental equipment of this work, and the schematic illustration of experimental apparatus used in this study as shown in Figure 2. It is worth noting that optical system magnification is 1 and the interval for each detector is 200μm.

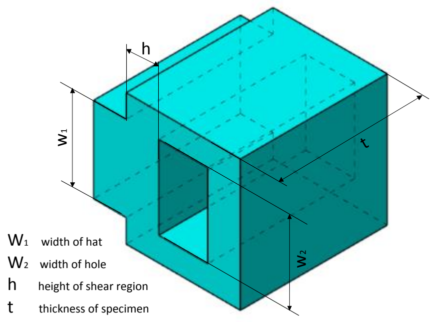

Fig.1. The flat hat-shaped specimen

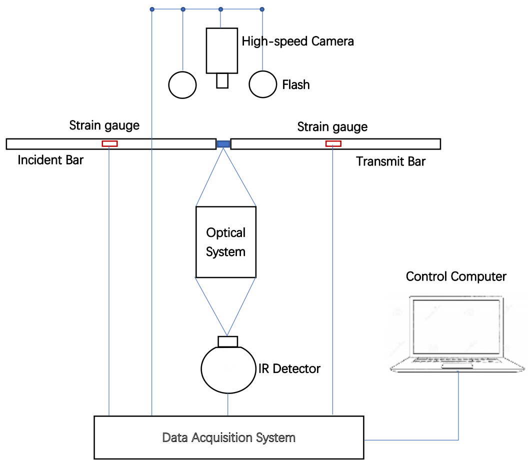

Fig.2. Arrangement of the SHPB apparatus combined with high-speed photography and temperature measurement system

Results and Conclusion

The mechanical properties of UFG TA2 titanium were obtained under quasi-static and dynamic loading, which were compared with those of CG pure titanium. Figure3 shows the deformation process of sample UFG-Test-11 taken from the high-speed camera. The deformation could be divided into four-stages: (1) Homogeneous deformation stage, (a) and (b), in which the sample is uniformly compressed; (2) Small inhomogeneous deformation stage, (c) and (d); (3) Severe inhomogeneous deformation stage, (e) and (f); (4) Shear failure stage, (g) and (h), where ASB is observed. The pictures were processed to get the critical strain (CS) for ASB initiation. Results show that the CS for UFG pure titanium is 0.37, which is much larger than its tensile failure strain (less than 0.05), indicating that the UFG material has good plastic deformation ability. The CS for ASB of CG pure titanium is 0.69. The temperature within ASB was in-situ measured and calculated. Results show that the temperature is between 300 to 700℃ and there is a sharp temperature gradient across the ASB.

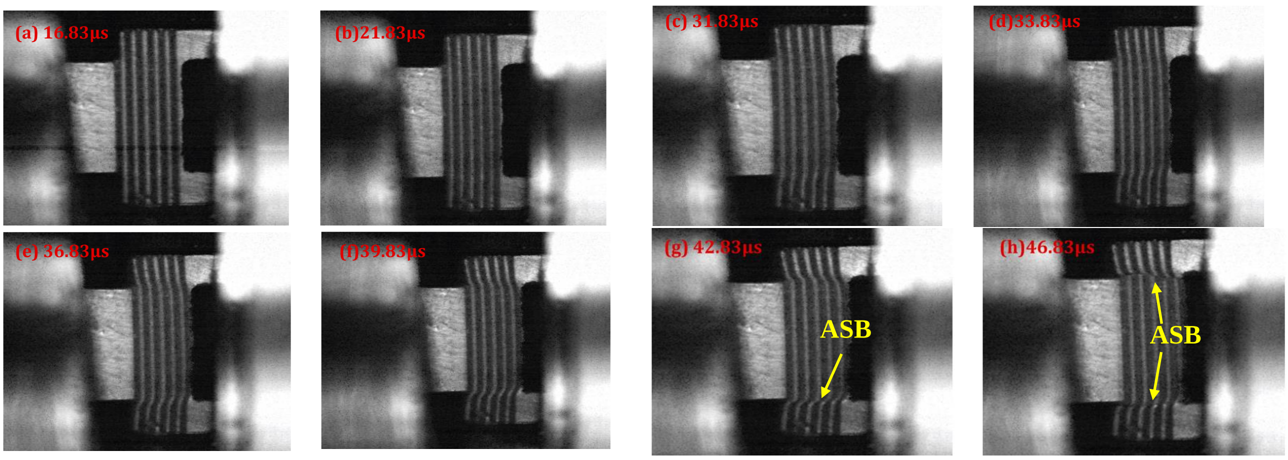

Fig.3 High speed deformation of a UFG titanium sample under impact loading.

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