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Microstructure evolution of depleted uranium impacted by steel projectile at velocity of 50 m/s

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Abstract: The deformed microstructure evolution of depleted uranium impacted by steel projectile at a velocity of 50 m/s was investigated by means of confocal laser scanning microscope, electron backscatter diffraction, transmission electron microscope and indenter technique. The experimental results showed that the spherical cap crater was formed in depleted uranium target impacted by steel projectile, and the diameter and depth of the impacted crater were 5.45 and 1.01 mm, respectively. From crater rim to deep matrix, four deformed zones were classified, including twin fragmentation zone, high density deformation twin zone, low density deformation twin zone and matrix zone. Twinning was considered as the dominant plastic deformation mechanism of depleted uranium subjected to impact loadings. Besides twinning, the dislocation slipping also played an important role to accommodate the plastic deformation. Finally, the deformed microstructure evolution of depleted uranium under high velocity impact was proposed.

Key words: depleted uranium; steel projectile; dynamic deformation; microstructure evolution; twinning

1 Introduction

Depleted uranium (DU) has been widely used in armor and armor penetrating fields due to its high density, high hardness and good self-sharpening property [1]. Broad applications in military fields, DU would be suffered from the impact loadings or shock loadings inevitably. Thus, it is necessary to obtain a fundamental understanding about plastic deformation process of DU subjected to impact loadings. However, high loading strength and short time of impact loadings lead to the real-time observation of dynamic deformation process difficultly [2], thus, the post-deformation microstructure characterization has been used to understand the impact evolution indirectly due to the fact that the deformed microstructures are closely related with the deformation process [3].

High stain rate and large stain provided by the impact loadings lead to appearance of various deformed microstructures in materials, such as dislocation microstructures, deformation twins, recrystallized grains, armorphization. Dislocation microstructures including dislocation cell, wall and microbands under impact loadings have been observed in face centered cubic (FCC) Al [4], Cu [5], Ni [6] and stainless steel [7]. Deformation twins including primary and secondary twins have been observed and confirmed in stainless steel under dynamic deformation [8]. The mixture microstructures composed of microbands and microtwins have been observed far from the crater in Cu [9] and stainless steel targets [7]. Dynamic recrystallized grains near the crater under high speed impact in Cu and Ni targets have been found by MURR et al [9,10]. Shock-induced localized amorphization in boron carbide has been observed by CHEN et al [11].

Though lots of works have been performed on the deformed microstructures in metals under impact loadings, limited results associated with the deformed microstructure in DU targets are available in previous references, especially microstructure evolution of DU subjected to impact loadings unclearly. Thus, it is necessary to investigate the deformed microstructures of DU under impact loadings. In addition, impact loadings can offer the gradient variation of the strain and strain rate from the crater bottom to the deep matrix, thus, the characterization of the deformed microstructure at different depths provides an important clue to elucidate deformed microstructure evolution of materials subjected to high strain rate and large strain loadings. In this work,

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the deformed microstructures at different depths in DU target under high velocity impact were characterized, and the corresponding deformed microstructure evolution of DU from the crater rim to the matrix was proposed.

2 Experimental

DU with thickness of about 30 mm was selected as the target. The DU target had the coarse grains with diameter ranging from several hundreds micrometers to several millimeters, and a number of impurities were found in DU target. High velocity impact was carried out on a gas gun using cylindrical penetrating steel projectile. The length and diameter of the penetrating projectile were 100 and 10 mm, respectively, and the spherical head with diameter 10 mm was used to penetrate DU targets. In order to decrease the air contamination and protect the experimenters, much lower impact velocity was used due to the fact that lots of aerocolloids would be produced in the process of uranium targets impacted by steel projectile. The impact velocity measured by laser device of 50 m/s was used in this work. After impact, the targets were sectioned along impact direction, mechanically polished and electrochemically etched in a 5% phosphoric acid water solution operated at 5 V and 30 s. The montage macroscopic views and metallographic microstructure of DU impacted by steel projectile were observed by a confocal laser scanning microscope (CLSM, MRC−1000). The specimens were prepared for EBSD observation using the procedure reported in detail in Refs. [12]. The automated EBSD data collection was performed using a TSL camera attached to a dual beam FIB (FEI Helios NanoLab DualBeam system) at a voltage of 25 kV. Thin sheets for transmission electron microscope (TEM) observation were cut parallel to impact direction, followed by mechanical polishing to a thickness about 50 μm. Final thinning to electron transparency was achieved by double jet polishing in a solution of 10 mL nitric acid +45 mL *n*-butanol + 45 mL methanol. The polishing voltage was kept constant at 30 V and the temperature was kept at −30 °C. The TEM observation was carried out with a F20 microscope operated at 200 kV. Following optical metallographic observation, Vickers microhardness was measured by microhardness tester. The load of 2 kg and a dwell time of 15 s were employed during microhardness measurement.

3 Results and discussion

3.1 Impact crater

Macroscopic views of a crater in depleted uranium target impacted by steel projectile at a velocity of 50 m/s are shown in Fig. 1. Severe plastic deformation around the crater can be observed in Fig. 1(a), and a few micro-cracks adjacent to the crater can be found. After high velocity impact, spherical cap crater is formed in DU target, as shown in Fig. 1(b). According to the measurement, the diameter (D_c) and depth (P_c) of the impacted crater are about 5.45 and 1.01 mm, respectively. High density deformation twins near the crater rim can be observed in Fig. 1(b), indicating that the deformation twin is an important plastic deformation mechanism of DU subjected to impact loadings. The formation of deformation twins in uranium under high velocity impact is associated with the crystal structure and stress levels. The crystal structure of alpha-uranium is orthorhombic (*Cmcm* space group), as shown in Fig. 2, and it is made up of corrugated sheets of uranium atoms parallel to the (010) or *ac* planes[13]. The depth or amplitude of corrugation within each sheet is along the [010] direction and the width of corrugation is along the [001] direction, and the separated distance of the corrugated planes is *b*/2 [14]. The strong anisotropy of uranium has been reported, and the ideal tensile strengths of uranium single crystal along [100], [010] and [001] were 21.3, 14.9 and 12.8 GPa, respectively [13]. Thus, the strong anisotropy assisted with severe plastic deformation leads to the formation of high density deformation twins [15,16], and the twinning, as an important plastic deformation mode, has been extensively observed and reported in DU under plastic deformation [17,18].

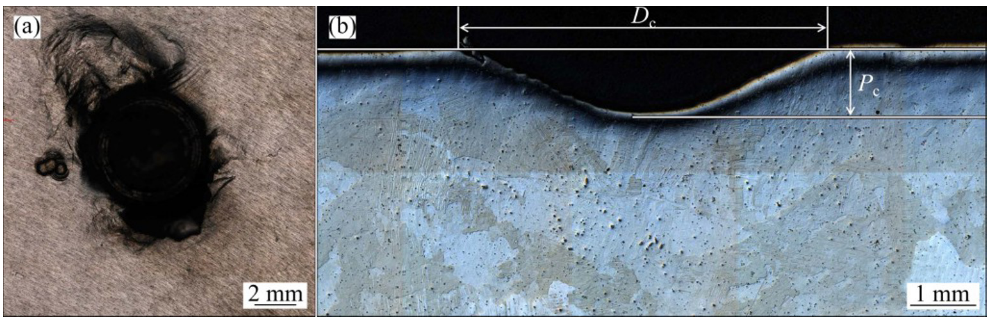

Fig. 1 Macroscopic views of crater in depleted uranium target impacted by steel projectile at velocity of 50 m/s: (a) Top view; (b) Corresponding cross-section view