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The influence of liner material on the dynamic response of the finite steel target subjected to high velocity impact by explosively formed projectile

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ABSTRACT: Subjected to high velocity impact(collision pressure over 30GPa) of copper and iron liner EFP, the finite steel targets experience the failure modes of plug and spall. Dynamic deformation and microstructure evolution of the finite steel targets are investigated in detail through ANSYS/LS-DYNA software and experiment methods including optical, scanning and transmission electron microscopy. Morphology analysis of fracture surfaces indicates that the copper EFP remainder plated to the crater wall shows extremely plastic deformation which consists of elongated parabolic dimples on the crater wall and the mild carbon steel target exhibits excellent brittle features that material fails mainly along the cleavage facets on the rear surface of target. The whole part of copper EFP remainder and partial material of steel target undergoes completely dynamic recrystallization, which displays an extreme plastic flow. The thickness of irregular DRX zone(30.4μm) formed by the interaction between iron EFP and steel target is wider than the thickness of DRX zone(21.3μm) formed by the penetration of copper EFP. Numerical simulation results indicate that the highest plastic strains at the crater wall can reach about 2 which can fully accommodate the grains deformation of steel target during the dynamic recrystallization process at strain rates of the order of 10^4 s^{-1}, and the average size of the refined DRX grains significantly decreases from 53.17 μm to approximately 200 nm. The refined grains in the DRX zone and elongated grains in the SPD zone distribute along EFP impact direction. Irreversible plastic deformation of grains extending from the crater wall to the matrix of steel target is consistent with the microhardness changes.

***Keywords*:** Liner material; Terminal effects; Numerical simulation; Fracture morphology; Microstructure evolution

1. Introduction

Explosively formed projectile (EFP) is a kind of shaped charge structure that demonstrates high penetration ability in weapon engineering [1,2]. A complete EFP warhead consists of a metallic liner, high-energy explosive (HE), case, a slotted ring or sleeve and a detonator[3]. After detonation, the EFP warhead liner undergoes extreme, yet controlled, plastic deformation driven by explosive[4]. As the appearance of projectile is stable, the velocity of EFP is about 1500-2500m/s in a long rod-shaped, with a high kinetic energy[5]. The various failure modes of target are caused by the kinetic energy of the projectiles, including perforation, plug, and spall[6-8]. When the projectile geometry and material changing, the target responds accordingly by accommodating deeper penetration for larger aspect ratio(the dimensionless ratio of length and diameter) of the projectile, and higher projectile densities relative to the target density(ρ_P/ρ_T)[9]. For small projectiles impacting semi-infinite or infinite targets(with thickness orders of magnitude greater than the projectile dimensions) at high velocity, the penetration into the target may be only a small crater which scales with the projectile diameter. However, the projectile is fragmented or eroded, leaving some fractional mass in the cratered target [10,11]. As the projectile dimensions and the thicknesses of target are in the same order of magnitude, the projectile striking a target effectively distributes its initial kinetic energy between itself and the target, as well as the plug from the rear of a target with finite thickness [12-14]. During high velocity impact by EFP, dynamic responses and damage modes of different targets are varied from each other according to the loads they are subjected to.

As a key component of EFP warhead, the liner experiences essentially plastic strains up to 300%, at strain rates of the order of 10^4 s^{-1}[15]. Therefore, the properties of the liner are important during the dynamic EFP formation process. The eventual effectiveness of the liner as a projectile is attributed to its high density, high ductility, high strength and sufficiently high melting temperature which prevent melting caused by adiabatic heating. Tantalum, copper, iron, molybdenum and tantalum-tungsten alloys have been used in EFP applications. A detailed microstructural analysis on Ta EFPs by Murr et al.[16,17] reveals that dynamic recovery (DRV) is a predominant mechanism influencing the EFP formation. Pappu[18]