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An experimental study on the projectile defeat mechanism of hard steel projectile against boron carbide tiles

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ABSTRACT

Failure mechanism of 7.62 mm AP projectile impacting boron carbide tiles was studied by post ballistic examination of the failed projectiles. It is found that the projectile failure originates simultaneously from at least two locations in the projectile during ballistic impact, one originating from the target interaction front of the projectile and another from a location near the tail end of the projectile. The failure origination from the target interaction front of the projectile is due to severe deformation at the interaction front. The second failure origination from locations near tail end of the projectile is due to stress wave generated micro-cracks. At the target interaction front of the projectile a temperature rise of above 1160 °C has been estimated. No remarkable change in failure mechanism of the hard steel projectile with respect to tile thickness (5–9.2 mm) or projectile velocity (600–820 m/s) has been observed. The variation in remnant projectile weight with respect to tile thickness and projectile velocity can be attributed to the change in duration of dwell or total projectile interaction time with ceramic target.

1. Introduction

Historically, ceramic composite armor systems were designed to defeat armor piercing (AP) kinetic energy projectiles mainly in small arms and heavy machine gun category [1,2]. The AP projectiles used in small arms are generally made with hard steel (HRc 60–64) core, but some are even made with harder tungsten carbide (WC) cores [3]. The projectile core is covered with a thin ductile metal jacket for interior ballistics or aerodynamic considerations [3]. The penetration performance of the bullet however is controlled only by the core properties [3]. Small arm projectiles usually have a length to diameter (L/D) ratio in the range of 3–5 with muzzle velocities of less than 1 km/s [3].

The projectile penetration and its failure mechanism on impact with brittle materials have been studied by many authors during the past two decades [4–12]. Michael et al. [4] used flash X-rays to capture the penetration event of 7.62 mm AP projectile into boron carbide target. They observed that while at 6 μs the nose of the projectile core eroded, the projectile did not penetrate into the ceramic. The projectile core started penetration into the ceramic material only between 16 and 25 μs. Leavy et al. [5] studied the dwell–penetration transition velocity with tungsten long rods into silicon carbide ceramic targets and found that the dwell–penetration transition velocity was primarily determined by the material properties and not by the thickness of the target. However, it was observed that the penetration-rate was influenced by the ceramic target thickness. In studies by Anderson et Al. [6,7] it has been shown that tile thickness has influence on duration of dwell, but duration of dwell is relatively independent on projectile velocity. As per Vlasov et al. [8], the penetration of hard projectile (L/D = 10) into ceramic target can be considered as a two stage process. During the first stage the penetration velocity increases as the ceramic is progressively damaged and during the second stage the penetration velocity reaches a quasi-steady state value where projectile penetrates into the failed ceramic. Sinani et al. [9] studied the penetration process of hard steel (hardness – 8 GPa) and WC (hardness – 17 GPa) projectiles in alumina and sapphire targets. They found that alumina and sapphire performed similarly against steel projectile. Against a WC cored projectile, the alumina target defeated the shot by fragmenting the bullet into pieces, whereas in sapphire the projectile perforated the target without being deformed. The inferior ballistic performance of sapphire against WC core was attributed to the decrease in sapphire hardness below WC hardness with increase in load.

It is important to understand that the projectile impact event is a high strain rate phenomenon, and the fracture patterns in high

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strain rate events are likely to be different from quasi-static fracture events because during high strain rate event, fracture is independently nucleated at many sites [13,14]. Further, in quasi-static conditions the surface/boundary defects (flaws) play a major role since the crack initiation takes place from those areas, whereas in high strain rate phenomena the spall fracture occurs at the interior of the body unaffected by the surface defects [14]. Therefore, the fracture morphologies observed in dynamic fracture process are expected to be different from quasi-static one.

Even though extensive literature on projectile penetration is available, not many studies pertaining to post ballistic examination on failed projectile have been published. In the present study, projectile failure mechanism of 7.62 mm AP projectiles when impacted against boron carbide tiles having different thicknesses and varying projectile velocities has been investigated. Detailed observations on the fracture surfaces as well as interior regions of the failed projectiles have been employed to identify the failure mechanisms.

2. Experimental

2.1. Projectile and target

The 7.62 mm AP projectiles used in this study consisted of a hard steel core covered with a copper sheath. The steel core had a diameter of 6.1 mm and a length of 28.4 mm with a mass of 5.3 g. The nominal weight of the projectile including the sheath was 10.4 g. Photographs of typical projectile with jacket along with hard steel core are shown in Fig. 1. The hardness of hard steel projectile is found to be 765 ± 7 VHN.

Tiles of boron carbide used in these experiments were of 40 mm diameter. Four different tile thicknesses i.e. 5 mm, 6 mm, 7 mm, and 9 mm were used to study the effect of target thickness for which a projectile velocity of about 820 m/s was used. The 6 mm thick boron carbide tiles were used to study the projectile velocity effect with 600 m/s and 700 m/s velocities. Aluminium alloy (6063-T6) blocks with 50 mm thickness were used as backing material for all the tests. The properties of boron carbide and backing material can be referred in our previous publication [15].

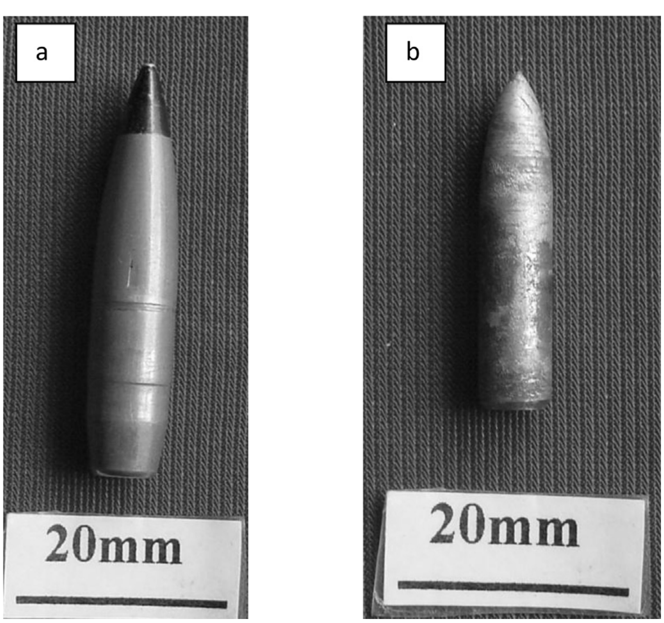

Fig. 1. Photograph of the 7.62 mm AP projectile (a) covered with copper jacket and (b) hard steel core without jacket.

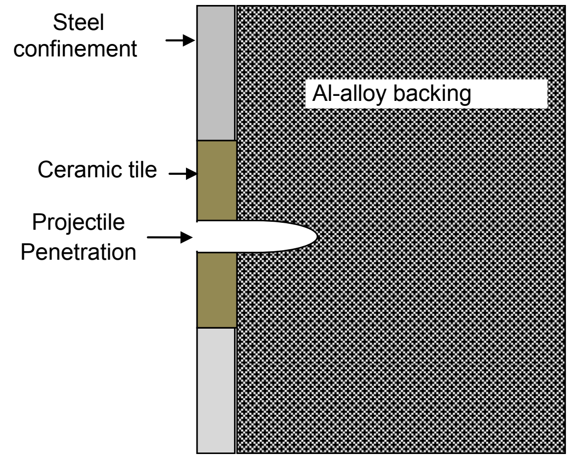

Fig. 2. Schematic of the hard steel projectile penetration process into the ceramic and Al-alloy target in DOP test configuration.

2.2. Ballistic test configuration

The DOP tests were conducted as per the configuration shown in Fig. 2. The detailed experimental setup has been described elsewhere [15]. The boron carbide tiles were tightly fitted in a steel confinement using brass shim and these confined tiles were placed over the aluminium alloy backing material without application of any bonding material. The 7.62 mm AP projectiles were fired at these targets from a rifled gun. The debris produced from the projectile and ceramic tile during ballistic impact event was collected using a front fabric covered steel box. The remnant broken shots present along with the collected boron carbide debris were separated using magnetic separation for further examination.

3. Results and discussion

3.1. Studies on the target interaction front of the projectile

A detailed post ballistic study on the target interaction front of the failed projectiles, after interaction with boron carbide and backing aluminium alloy, was carried out. A typical failed projectile after ballistic impact is shown in Fig. 3. The projectile is intact along its longitudinal axis and failure is observed only at the target

Fig. 3. Failed 7.62 mm AP projectile after ballistic impact with 5 mm thick boron carbide tile backed by Al6063 alloy.