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Development of Tungsten Heavy Alloy with Hybrid Structure for Kinetic Energy Penetrator

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Abstract

A new tungsten heavy alloy with hybrid structure was manufactured for the kinetic energy penetrator. The tungsten heavy alloy is composed of two parts: core region is molybdenum added heavy alloy to promote the self-sharpening; outer part encompassing the core is conventional heavy alloy to sustain severe load in a muzzle during firing. From ballistic test, it was found that the penetration performance of the hybrid structure tungsten heavy alloy is higher than that of conventional heavy alloy. This heavy alloy is thought to be very useful for the penetrator in the near future.

Keywords : Tungsten heavy alloy, Penetrator, Hybrid structure

1. Introduction

A kinetic energy round defeats a target by penetrating an armor with the kinetic energy of penetrator. Tungsten heavy alloy(WHA) or depleted uranium(DU) is used as penetrators in all cannon-fired kinetic energy projectiles. The DU penetrator is manufactured by casting and forging [1]. The WHA projectile is fabricated through powder metallurgy techniques.

Despite the superior performance of the DU munitions [2], there are many environmental concerns, political controversies and additional costs associated with their manufacture, their use in the battlefield, the subsequent battlefield clean up which may be required, and the final disposal of these rounds. These concerns have prompted counting efforts to develop a less hazardous, environmentally more benign, tungsten based penetrator material which is capable of equalling or surpassing the performance of DU [3].

In the present investigation, we proposed a tungsten heavy alloy penetrator with hybrid structure which exhibits excellent penetration performance. Material properties and microstructure were also investigated. The penetration performances of the conventional WHA penetrator and the hybrid one were compared by a ballistic test to evaluate the applicability of this new material to a kinetic energy projectile.

2. Experimental and Results

Two types of specimens, a conventional and a hybrid structure heavy alloys, were prepared from W, Mo, Ni and Fe elemental powders with 2.5, 2.5, 3.0 and 3.5μm in average size, respectively. The conventional heavy alloy was used as a reference specimen. Its composition was 93W-4.9Ni-2.1Fe and was fabricated by the usual powder metallurgy processes.

A schematic drawing of a hybrid structure WHA penetrator is shown in Fig.1. The composition of the core material was 92.8W-4.6Mo-1.1Ni-1.5Fe. The mixed powder was compacted under 200MPa into a round bar and then sintered under hydrogen atmosphere at 1425°C for 2 hours. Sintered core material was positioned at the center of a rubber bag for cold isostatic pressing with a fixture. Mixed powder for the housing material, 90W-7Ni-3Fe in composition, was packed around the core and compacted. The compact was sintered under hydrogen atmosphere at 1475°C for 2 hours. The sintered specimen was heat-treated and cold working of 18% area reduction was carried out to increase the strength of the material.

Ballistic test was conducted with a solid propellant gun. Its caliber was 30mm. Projectiles were made of WHAs with a conventional and a hybrid structures. The striking velocity measured by MVRS(Muzzle velocity Radar System) was about 1140m/sec.

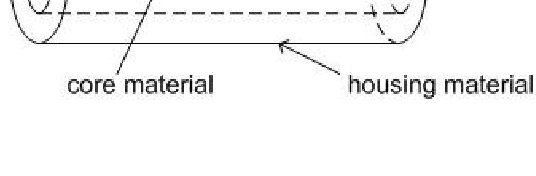
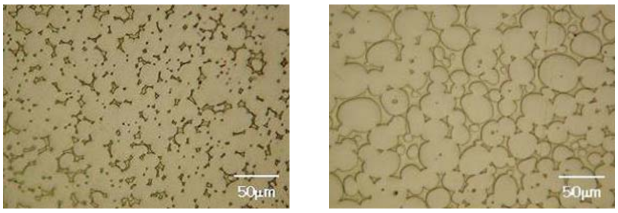


Fig. 1. Schematic drawing of a hybrid structure WHA penetrator. Brittle core induces self-sharpening and housing material sustains structural integrity.

The microstructures of the core and the housing materials after they were sintered together are shown in Fig.2. The tungsten particle size of the housing is larger than that of the core. It is noted that tungsten particle growth of the core also occurred. This seems to be the result of fully developed liquid phase sintering at the final sintering step which was carried out at higher temperature than that of the first one. The chemical analysis found about 10.5% molybdenum in weight in the core material. However, no trace of molybdenum was detected in the housing. So it can be thought that the difference in tungsten particle size in the core and the housing was resulted from the presence of molybdenum which altered the chemical composition of the matrix.[4] The sintered density of the conventional and the hybrid structure WHAs were 17.74g/cm^3 and 17.29g/cm^3, respectively.



(a) (b)

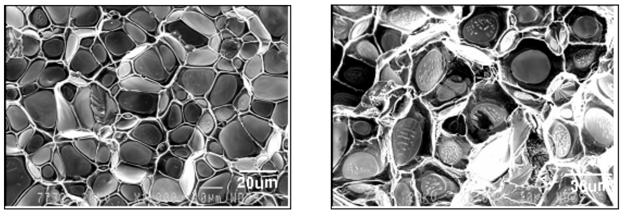
Fig. 2. Final microstructure of core and housing materials. (a) Core and (b) Housing.

The fracture surfaces of the hybrid structure WHA were shown in Fig.3. The brittle intergranular fracture was revealed in the core material, which showed no ductile failure of the matrix. The brittle fracture mode is expected to lead to self-sharpening during penetration. On the contrary, the housing material showed ductile fracture behavior. The housing material is thought to be able to maintain the structural integrity of the projectile inside a gun bore and at the impact.

The hybrid structure penetrators were found to have improved penetration performance over the conventional ones showing 10% increase in penetration depth.

It has been reported that the undulation of tungsten particles in WHA increased the penetration depth.[5] In this heavy alloy, the failure mode was observed to be brittle transgranular fracture.

The change from ductile fracture to brittle one is caused by protrusions or intrusions of the particles since they act as stress-concentration points like notches. The brittle fracture in WHA was known to be beneficial to penetration performance because brittle fracture results in self-sharpening of the penetrator [6]. Hence, it can be inferred that the fracture behavior of the core material induced self-sharpening and contributed to the increased penetration of the hybrid structure WHA in spite of decrease in the density.



(a) (b)

Fig. 3. Scanning electron micrographs of fracture surface of hybrid structure WHA. (a) Core - Brittle fracture and (b) Housing - Ductile fracture.

3. Summary

According to a new concept of combining brittle core material to ductile housing, a hybrid structure WHA penetrator was fabricated by powder metallurgy techniques. The core material showed brittle intergranular fracture while the housing material exhibited ductile one, typical in conventional tungsten heavy alloy. The penetration depth of the hybrid structure WHA penetrator was found to be higher than that of the conventional one by 10%. The self-sharpening of the penetrator resulted from brittle fracture of the core contributed to the increased penetration performance of the hybrid structure projectile.

4. References

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