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Analysis of morphology and microstructure of B_4C/2024Al composites after 7.62 mm ballistic impact

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ABSTRACT

The effects of ballistic impact on morphology and microstructure of B_4C/2024Al composites were studied. B_4C/2024Al composites with 55% volume fraction of B_4C particles were prepared by pressure infiltration method, and the experimental test of ballistic performance of composites was carried out by 7.62 mm armor piercing projectiles. The obvious upsetting of bullet and furrows on bullet tip are generated after bullet impact. Moreover, bared B_4C particle distributes uniformly on the bullet surface, indicating that the composites target plays roles of passivation and abrasion on bullet. The protection coefficient of B_4C/2024Al composites shows trends of falling, then an upward trend, at last keeping constant as the increasing thicknesses of targets, and could reach up to 2.8. For the composites target with semi-infinite thickness, three kinds of failure morphology are presented at the bullet crater: caving, erosion and melted areas, spreading successively as the increasing depth, which indicates that the interaction between bullets and targets is different at different stage of bullet penetration. Interestingly, the interface bonding of composites keeps well after bullet impact; moreover, no interface de-bonding was observed. High density of dislocation is generated in Al matrix around the interfaces, meanwhile, dislocations and micro-cracks were found in some B_4C particles.

1. Introduction

Generally, materials used for Armor protection are classified into three categories: metals [1,2], ceramics [3,4], fiber reinforced composite laminated plates [5,6]. Metal armors, such as 603 armor steel and 7A52 armor Al, present numbers of advantages, namely easy machining, low cost, strong resistance to multiple bullets and no secondary damages. However, the protection capability of metal armors is relatively low. Fiber reinforced composites show advantages of low density, high strength, which could effectively decrease cracks of the backing materials. Nevertheless, fiber reinforced composites could not be used independently because of low strength and high cost. Therefore, the following applications, such as strengthen backing of metal targets or interlayer of composite laminated plates, are promising.

It is known that ballistic protection capability of metal armors could be effectively improved through covering a layer of ceramic plate. Therefore, the ceramic armors, namely Al_2O_3, SiC, B_4C and TiB_2, have greatly developed since last century, which show promising ballistic protection capability. However, the ceramic armors, with disadvantages of high cost, difficult machining, low fracture toughness and low-resistance to multiple bullet impacts, could not achieve actual applications as independent ballistic armor. Therefore, much attention has been attracted to further improvement of the disadvantages of ceramic armors, and there have been mainly two approaches: composite structures and composite materials.

Commonly, the protection capability of normal materials could be effectively improved through composite structures of ceramic/metal or ceramic/fiber. Lee [7] calculated the ballistic performance of Al_2O_3/Al composite structure and obtained the failure models under different conditions. Abu Talib [8] tested the ballistic limitation of Kevlar-29 and Al_2O_3 power/epoxy armors, which present promising energy absorbing capability. Ubeyli [9] prepared the Al_2O_3(6 mm thickness)/dual phase steel composite targets; interestingly, the ballistic performances impacted by armor piercing bullet with 7.62 mm diameter have been greatly improved. However, the content of martensite phase of dual phase steel has little influence on its ballistic performance. Nowadays, composite structure armors have attracted widely attention, and some applications

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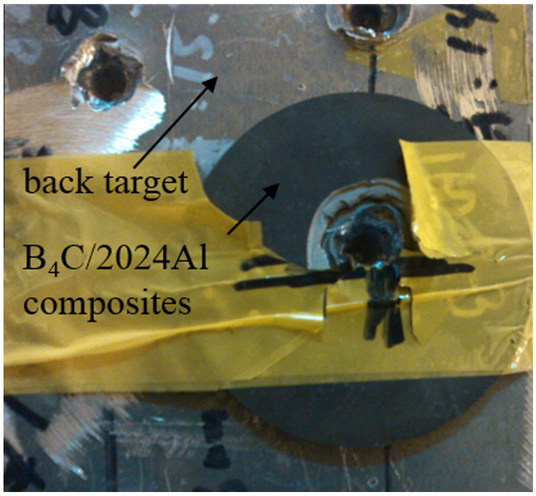

Fig. 1. Test target for ballistic performances of B4C/2024Al composites.

have been achieved, such as the B_4C and Kevlar composite armors were used in chairs of Blackhawk Helicopters. However, the inherent shortcomings of ceramic armors should be further improved.

Interestingly, it is an effective way to improve the toughness and reduce the cost of ceramic armors through composite materials. There have been more advantages of metal matrix composites (MMCs) armors than ceramic armors; however, there are also some difficulties for MMCs development as functionally graded armor composites [10]. The failure and wearing mechanisms of SiC/Al composites, impacted by armor piercing bullet of 7.62 mm diameter, were discussed by Karamis [11], indicating that the great wearing process by composites could lead to reduction of penetration depths. Furthermore, the influences of volume fractions of MMCs on ballistic performance were investigated [12]: more cracks would be produced for the higher volume fraction of MMCs by the bullet impact. After ballistic impact, the surface characterizations of 20% Al_2O_3/Al were characterized [13], interestingly, damaged or plastic deformation were observed on the tip nose of bullet, and furrows were generated on the surfaces of bullets by the friction of bullet and the harder target plate. Moreover, the metallurgy and deformation behaviors of laminated metal matrix composites after ballistic impact were studied in [14], and the protection capability of two types of laminated MMCs was discussed.

There are commonly two bulletproof mechanisms for the MMCs targets: damage or plastic deformation of bullets, and dramatic friction between bullets and targets. Therefore, hard B_4C particles are introduced in MMCs for the following reasons: on the one hand, the deformation mechanisms of MMCs targets are improved for increasing hardness; on the other hand, the friction work between bullets and targets is also increased. It is known that decreasing diameters of B_4C particle could improve the crack production in particle. Therefore, reinforced particles with smaller size are promising for MMCs. Moreover, increasing volume fraction of reinforced particles could increase the hardness of MMCs, thus could further improve the ballistic performance of MMCs targets. However, there have been only few reports on microstructure of MMCs after ballistic impact [15,16]. Here, the influence of ballistic impact on morphology and microstructures of B_4C/2024Al with 55% volume fraction was discussed. Moreover, the micro-mechanisms of bulletproof for the MMCs target were also studied.

2. Experimental details

B_4C/2024Al composites, with 55% volume fraction of B_4C particle, were prepared by pressure infiltration method. The B_4C particle with average size of 17.5 μm was chosen. Heat treatments were introduced as following: solution treatment at 495 °C for 1 h,

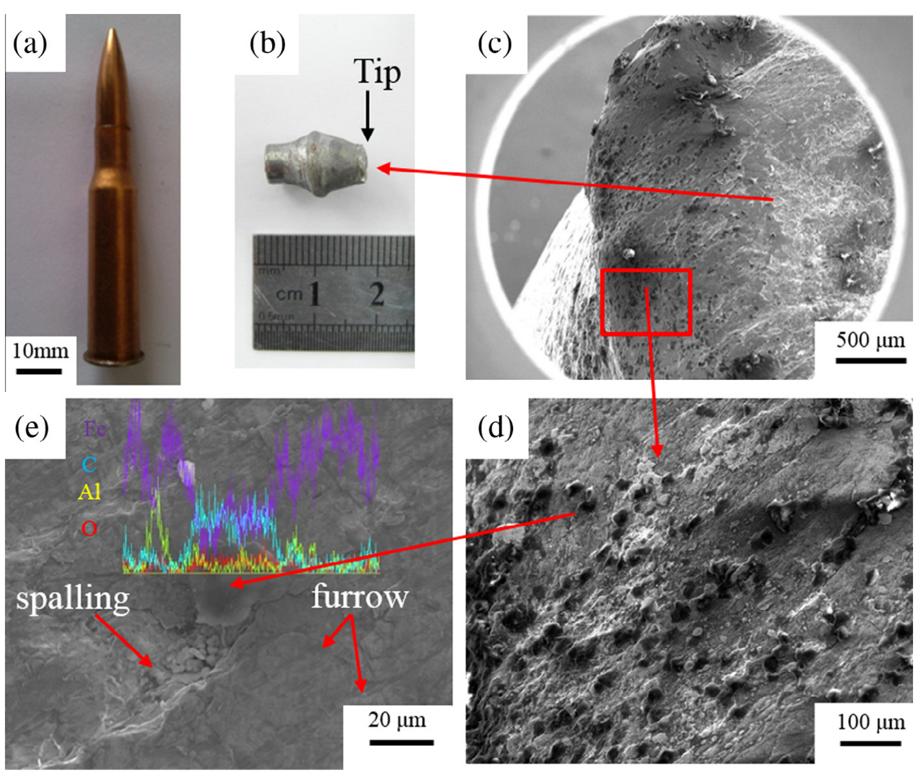

Fig. 2. Micro-morphology and composition of bullets after impaction on composites target. (a) the original 7.62 mm × 51 mm armor piercing bullet; (b)armor piercing bullet after impaction on composites target; (c) SEM morphology of bullet tip; (d) energy spectrum analysis of black particle and typical spalling and furrow area; (e) black particle distributing uniformly on bullet surface.