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Experimental study on the performance of woven fabric rubber composite armor subjected to shaped charge jet impact

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ABSTRACT

In this work, the protective capability of different types of woven fabric rubber composite armors (WFRCAs) are evaluated using the depth of penetration test method against a 56 mm-diameter shaped charge. Carbon, glass, Kevlar, and poly (phenylene benzobizoxazole) (PBO) woven fabrics are used as the reinforcement. The effect of the type of woven fabric on efficiency factors is studied. To provide appropriate benchmarking, the bulging armor and layered steel armor are also used in the DOP experiment. The Kevlar WFRCA is found to be more suitable as an add-on armor compared with carbon, glass, PBO WFRCAs, bulging armor and layered steel armor. The flash X-radiograph is used to visualize the deformation of jets as they penetrated the different types of WFRCAs. The effects of the number of jet bulges, the disturbance amplitude and frequency on the jet, and the length of the jet tip precursor are analyzed and discussed. A greater the bulge number is found to result in greater disturbance amplitude and higher disturbance frequency, thus generating more serious jet disturbance. Finally, with respect to the deformation of woven fabric after the jet impact, the results indicate that for carbon, glass, and Kevlar woven fabric, the damage regions are similarly rectangular or rhombic, but distinct from the PBO woven fabric.

1. Introduction

High-speed metallic jets are propelled out of conical cavities when loaded with explosive shock waves, and these shaped charge jets exhibit high penetration capability, a major issue for armor designers worldwide. One of the most efficient ways of disturbing a metallic jet is by allowing it to interact with an oblique moving plate. Explosive reactive armor (ERA), essentially comprising two steel plates sandwiched around a high explosive layer, has been demonstrated to be one of the most effective add-on armors against high-velocity jets from shaped charges [1–3]. However, in the application of the ERA, the necessary space for the plate movement should be available. The problems attributed to the undesired interaction of the moving plates with the main armor and the environmental damages are inherent to these systems [4]. The fragments emanating from the explosion of the ERA increases the danger for troops near the exploding cassette [5].

This aspect has motivated studies on bulging armor. Bulging armor is a non-explosive reactive armor comprising a layer of an inert material (usually rubber) sandwiched between two metal plates. When a shaped charge jet strikes obliquely at a bulging armor, the metal plates, during the bulging process, collide with the jet and disturb it. It is effectively used to protect a main armor against a shaped charge jet [6,7]. The description of the mechanisms of these bulging systems was first proposed by Gov [8]. Although the bulging armor is not as effective as the ERA, the bulging armor offers essential advantages over the ERA. It is safe and causes no environmental or local damages [9]. The main mechanism in the acceleration of the metal plates is the high pressure developing in the rubber layer, during the jet penetration and the lateral movement of the rubber, which forces the metal plates apart. Thus, the major defeat mechanism of the bulging armor is similar to explosive reactive elements [10]. Held roughly analyzed the disturbance frequency of an armor comprising a steel plate and a layer of Dyneema fibers through a flash X-ray experiment. The paper described two “new” base inert materials, using Dyneema instead of rubber in the layer [11]. A layer of rubber, which will gasify, or even explode, is regarded as an inert explosive. A mechanism for the interaction based on the theory of Kelvin–Helmholtz instabilities was discussed by Helte [12].

At present, woven fabric reinforced composites are among the most important and widely used forms of ballistic impact-resistant and armor protection materials. Depending on the class in which they belong, different fibers present different structural properties,

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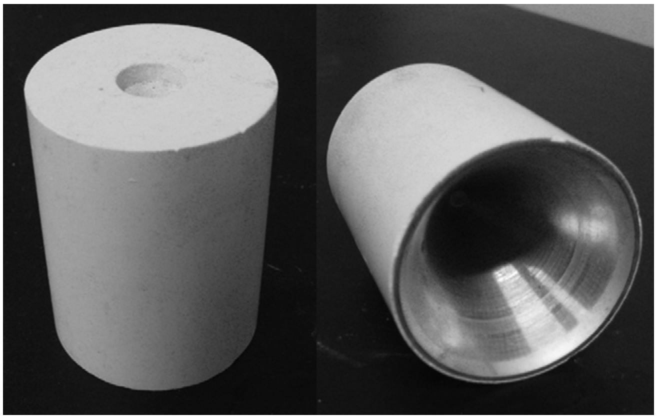

Fig. 1. Photograph of the shaped charge with a diameter of 56 mm.

resulting in different responses to ballistic impact when woven into fabric. Some examples are aramids, such as carbon, glass, Kevlar, poly (phenylene benzobizoxazole) (PBO) fibers, and ultraheavy molecular weight polyethylene [13–15]. Carbon, glass, Kevlar and PBO woven fabrics have been introduced as attractive reinforcement materials, providing excellent integrity and conformability for advanced structural composite armors [16–18]. These high-performance fibers are characterized by low density, high strength, and high energy absorption.

In the case of woven fabric reinforced rubber armor plates, however, the mechanisms are significantly more complex because of the interaction between the woven fabric and the shaped charge jet. Hence, in this paper, we propose the utilization of these four types of woven fabrics in rubber composite armors to enhance ballistic protection. The comparison of the protection capabilities of these four types of woven fabric reinforced rubber composite armor plates and the analysis of the interaction and the origin of the disturbances on the jet are the major goals of this study. Experimental data comparing the residual penetration of a shaped charge jet after interacting with the woven fabric reinforced rubber composite armor are first presented. To study the iterative interaction of the plates with the jet in more detail, two 450 KV flash X-ray apparatus were used for the registration of the passage of the jet through the armor plates.

2. Experiments

2.1. Used shaped charges

The shaped charge used in these experimental trials has an outer diameter of 56 mm and a length of 73 mm, with a 0.8 mm copper liner and 60° cone angle, with 8701 explosives weighing

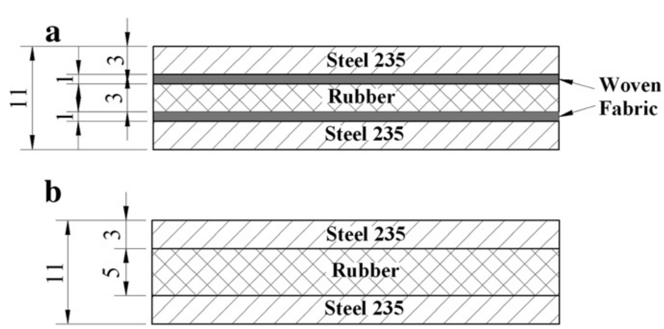

Fig. 2. a. Schematic of the WFRCA (all dimensions in mm). b. Schematic of the bulging armor (all dimensions in mm).

203 g without the shell cover. The 8701 explosive has a density of 1.713 g/cm^3 and detonation speed of 7980 m/s. The penetration of this shaped charge at 340 mm (roughly 6 calibers) standoff in RHA is 160 mm. This particular shaped charge produce a reproducible metal jet with low fragmentation, thereby making it ideal for use in conjunction with velocity instruments. In all cases, the standoff measured from the shaped charge to the woven fabric rubber composite armor (WFRCA) target was 80 mm (roughly 1.5 calibers).

2.2. WFRCA construction

Each WFRCA configuration comprised the following layers: steel, woven fabric, rubber, woven fabric, and steel. This symmetric configuration utilizes the combined effect of both the woven fabric and rubber element against a shaped charge jet. Two of the woven fabric layers were placed in intimate contact with the two sides of the rubber layer. We applied a premium grade adhesive to bond the steel plates and the woven fabric layers. The thicknesses of the steel plates, woven fabric, and rubber layer were 3, 1, and 3 mm, respectively. The WFRCA had an areal geometry of 150 mm × 300 mm. Fig. 2 a details the schematic of the WFRCA Fig. 1.

Four candidate materials were chosen for the woven fabric layers. In each case, two firings were conducted with the carbon, glass, Kevlar, and PBO WFRCAs, respectively. These double firings were conducted to ensure that the effectiveness of each composite armor that interacted with the shaped charge jet was broadly similar. Moreover, these firings were conducted to ensure the measurement of two effective penetration depth values. A summary of the woven fabric materials used, with their density, weave, thickness, layer number, and a number of properties, is provided in Table 1.

To provide the appropriate benchmarking to evaluate the effect of the fabric additions, the bulging armor comprising a layer of rubber (5 mm thick) sandwiched between two metal plates (3 mm thick) was used in the DOP experiment. To improve the benchmarking further, a similar configuration of armor plates, but with a layer of 5 mm thick steel plate to replace the rubber was also used in the DOP experiment. Fig. 2b details the schematic of the bulging armor. The properties of rubber and steel plate used in the experiment are provided in Table 2.

2.3. Depth of penetration (DOP) experiment

To investigate the protective capabilities of different types of woven fabric reinforced rubber armor plates against shaped charge, the DOP method was used in the experiment. A Schematic diagram of the sides of the DOP test configuration is shown in Fig. 3. Given the velocity gradient along the jet direction of movement, the jet tip velocity has a direct bearing on the DOP. To study the mechanism between the shaped charge jet and WFRCA, measuring the jet tip velocity is important. The interval between the interceptions attributed to the jet running across two copper foils placed on the F-plate and RHA-witness blocks was then used to calculate the velocity. The velocity measurement system accuracy is 0.1 μs. At a 340 mm distance standoff to the shaped charge, RHA-witness blocks were set to measure the depth of the residual penetration capability of the jet disturbed by plates. Fig. 4 details the DOP test setup.

2.4. X-ray setup

The shaped charge was vertically installed in a standoff 80 mm to the front of the WFRCA. The WFRCA was arranged under a 60° NATO-angle to the shaped charge axis. The shaped charge and WFRCA were lifted using a cotton rope. Two 450 kV flash X-ray