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Experimental investigation of the response of gelatine behind the soft body armor

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ABSTRACT

Understanding the transient cavity formation and transient pressure in the behind armor blunt trauma (BABT) is of fundamental importance in various research fields.

In this paper, the transient response of ballistic gelatine behind the soft body armor subjected to the impacting of pistol bullets was studied. The profiles of the transient cavity in real time were captured by a high-speed camera, while the transient pressures were simultaneously recorded by pressure gauges. We find the cavity expansion–contraction movement is self-similar and can be expressed as a semi-ellipse. The gauges-recorded pressures reveal that three peaks on the pressure–time curve.

1. Introduction

Body armor is an important individual equipment that could prevent the bullet impacting the body tissue from a penetrating gunshot. The bullet is possibly prohibited from penetrating the body by high-performance fibers (e.g. Kevlar®, Dyneema®, Zylon®) with high energy absorption ability. Although most of the kinetic energy stored in the bullet would be absorbed by the abruption and deformation of the fibers, the armor-released energy may be transferred to the body to produce the behind armor blunt trauma (BABT) with the pressure impulse and transient cavity [1,2]. Death with very high energy impacts may occur, since the stress may exceed the strength of body tissues and the organs (e.g. thorax, lung, liver).

Since the existence of BABT was reported in 1970s, BABT was extensively explored through experimentations and simulations [3–8]. In early experiments, the main targets as the living organism were animals due to the ethical limitations and legal prohibition in most countries. In recent years, simulated body tissues (e.g. synthetic rubber, soap, clay), especially ballistic gelatine, were introduced into the experiments and simulations because of some human-body-like physical characteristics and mechanical response [9–11]. Van Bree et al. reviewed both experimental and simulation studies on this problem and proposed the 'twin peak' in the blunt impact [3–5]. Bugarin et al. [12] investigated the impact wave in the experiments of simulated body tissues with textile, and studied the effects in the experiments. However, those experiments were conducted with a shock tube. Also a simplified model consisting of muscles, bones and lung but without detailed geometry was built to investigate the response of pressure impulses on the lung [13]. The study shows the responses of the lung at the duration time of pressure. Cavity, a typical phenomenon in BABT, was also studied experimentally [14,15]. These studies quantified the energy transferred to the backing material and proposed a method to evaluate the injury in BABT. However, these studies were all conducted with clay and did not consider the evolution of transient cavity.

Transient cavity and pressure are two important features in BABT. Thus, in our experiments here, we consider the soft body armor made from ultrahigh molecular weight polyethylene (UHMWPE) fibers and placed in front of ballistic gelatine – a simulated body tissue. The transient cavity and transient pressure were studied with a high-speed camera and four pressure gauges, respectively. The main aim was to elucidate the cavity evolution and pressure propagation.

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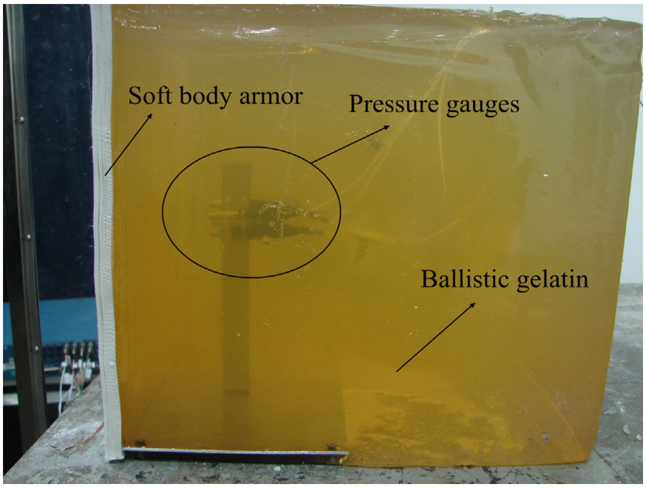

Fig. 1. The materials in the experiments.

2. Experimental set-up

Experiments were carried out in a 100-m-long ballistic lane. Some facilities were conducted to investigate the transient behaviors of ballistic gelatine behind the soft body armor. During the experiments, impact velocities and pressures in gelatine block were measured. Besides, transient cavities in the gelatine were recorded to analyze the cavity evolution.

2.1. Materials

The studied materials include a soft body armor and a ballistic gelatine block (10 wt% at 4 °C) (Fig. 1). A commercial level IIIA (NIJ standard) soft body armor (NingBo Dacheng Advanced Material Co. Ltd., China) was used. This armor is a 300 mm × 300 mm panel of 46 UHMWPE-fiber layers, and each layer consists of four plies of UHMWPE fibers which are formed into a [0°/90°/0°/90°] stack. Each sheet is nominally 0.2 mm thick without adhesion between layers. All armors used here were from the same batch.

The ballistic gelatine (10 wt% at 4 °C) was made of collagen powder, and its preparation is detailed in Ref. [16]. Liquid gelatine at 60 °C was put into a 300 mm × 300 mm × 300 mm mold with four pressure gauges (Fig. 1). In order to reduce the temperature effect, we kept the ballistic gelatine in a refrigerator at 4 °C before the experiments.

2.2. Experimental set-up and procedures

Two groups of experiments were conducted: (1) 220 ± 10 m/s and (2) 360 ± 10 m/s. Ballistic experiment facilities included a launch system, a velocity-measuring system, a high-speed camera, targets and a pressure-measuring system (Fig. 2). A 9 mm ballistic gun and 9 mm × 19 mm Parabellum bullets were used in the shootings. The exit of the muzzle is 5 m distance from the targets along positive *Z* direction. The point of bullet impact was aligned with a red dot. The amount of gun powder in a bullet was determined from the speed measurements in the preliminary experiments. In the experiments, the impact speeds of bullets were measured by an XGK-2002 speed-measuring system.

During the experiments, the cavity formation and evolution were recorded by a Phantom V710 high-speed camera positioned perpendicular to the projectile ballistic trajectory. Two images with a resolution of 640 × 384 pixels of the time interval for 9 mm bullet is 43 μs. In addition, an LED as a light source, placed on the other side of the gelatine block, was synchronized with the velocity measurement. When a bullet was passing through the 1st or 2nd test target, a digital voltage was triggered and simultaneously sent to the LED, which was lighted up to provide enough light for the camera.

The soft body armor was placed in front of a gelatine block, and the dimensions of *x* and *y* axes on the contact surface were constant. Four pressure gauges (locations showed in Fig. 3) embedded in the gelatine block provide the pressures up to a distance 40 mm from the impact face of gelatine. The four gauges were fixed in a bracket to form a 25 mm × 25 mm square. An ICP 113B22 pressure sensor (PCB Piezotronics Inc.) with a measurement range of 400 kHz and 0–69 MPa was used.

3. Results and discussion

Results were recorded after each shoot. Images of bullet–target interaction were taken by the high-speed camera, while the transient pressures from the impacting surface to 40 mm in gelatine were measured by the four pressure gauges.

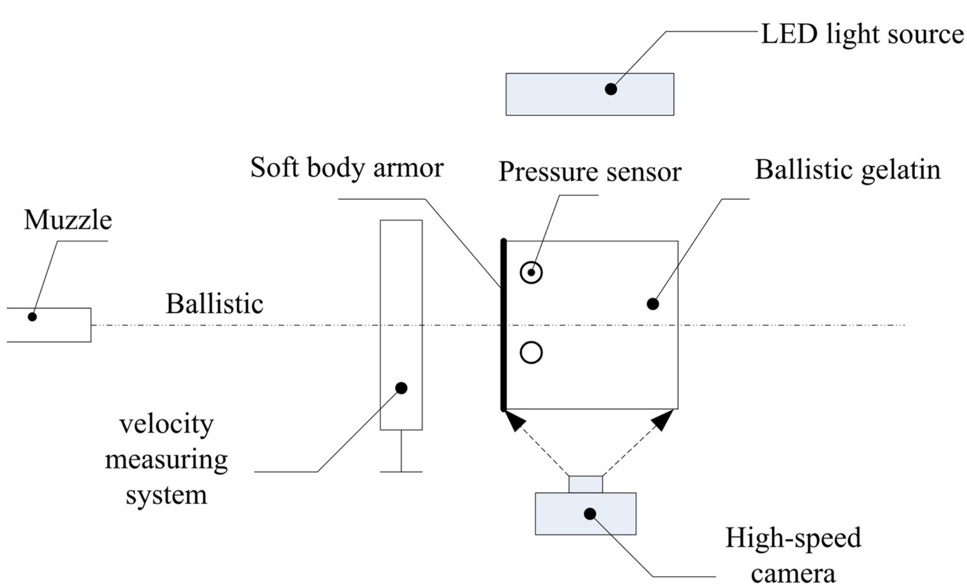

Fig. 2. Experiment system.