Effect of backing material on the ballistic response of skin simulant against fragment-simulating projectiles

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I. INTRODUCTION

Skin serves as the human body's first line of defense against any external mechanical loading. The ballistic response of skin against projectile impact is vital from the perspective of protection and lethality. Skin-penetrating injuries are considered lethal penetration; hence skin penetration criteria are used to evaluate a projectile's effectiveness [1]. In modern tactical warfare, the majority of penetrating skin injuries are caused by fragments generated from warheads, ground mines, hand grenades and improvised explosive devices (IEDs) [2]. Even though the fragments are major contributors to penetrating skin injuries on the battlefield, most of the literature focuses on larger projectiles, such as bullets [3].

Testing of skin in a controlled laboratory setting poses several challenges, such as the source of skin, storage conditions, heterogeneity, and ethical issues. Accordingly, physical simulants are preferred for experiments. Further, the skin simulants can be used either isolated or backed by other biological phantoms representing underneath tissues. Testing isolated skin simulants facilitates direct comparison of the simulant and corresponding tissue without additional effects, such as backing material. On the other hand, simulants backed with other biological phantoms, such as bone, brain, or muscle simulants, give responses close to that of the corresponding organ. This study aims to investigate the effect of backing material on the ballistic response of a synthetic skin simulant.

II. METHODS

Materials

A two-part, silicone-based compound (Smooth-On Inc, USA) was used to prepare the skin simulant. Both parts of the silicone material were mixed in equal proportion, stirred thoroughly, poured into a mould for curing, and left for 16 hours. This skin simulant possesses a shore hardness of 30A and provides a stress-strain response similar to human skin [4]. The sample was prepared in a squared cross-section with a thickness of 3 mm and sides of 125 mm (Fig. 1). The thickness of 3 mm was selected on the basis of the average thickness of human skin available in the literature [5]. For backing materials, a bone-like modified polyurethane plate (Synbone®) was used as the bone simulant, and a 10% gelatine block was used to represent underneath soft tissues. Synbone® plate is widely used as a bone surrogate in ballistic testing due to matching elastic modulus and macroscopic fracture pattern [6] and 10% gelatine is commonly used as a simulant for underneath soft tissues, such as the brain and muscle [6]. The 6 mm thick Synbone® plate and 150 mm thick gelatine block were stacked together behind the skin simulant to mimic the human head.

Experiment

A pneumatic gas gun was used to launch the fragments. To standardise the experiments, we used NATO recommended chisel-nosed fragments simulating projectile (FSP) of mass 1.10 g (Fig. 1). The 1.10 g FSP was chosen because it is the standard fragment used in the assessment of body armours [7]. The velocity of FSP was controlled by altering barrel length and air pressure. A high-speed camera (Phantom v411, Wayne, NJ) was used to capture the interaction of the fragment with the skin simulant, and these images were utilised to calculate the fragment velocity. The skin simulant was investigated regarding ballistic limit velocities (V_{50}), interaction mechanics, and failure pattern. V_{50} calculation was done according to NATO STANAG 2920 [8], which defines V_{50} as the mean of six velocities (three maximum velocities corresponding to non-perforation and three minimum velocities corresponding to perforation).

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III. INITIAL FINDINGS

The V_{50} values corresponding to skin simulant perforation in the isolated case and skin with bone simulant perforation in the backed case were 86 m/s and 175 m/s, respectively (Fig. 2). The mechanics of interaction were similar in both cases. Skin simulant failed by the combination of shearing and elastic hole enlargement. The generated cavity in the skin simulant was smaller than the FSPs' diameter. However, the shape of the cavity was different in both cases. A circular-shaped cavity was generated in the isolated skin simulant, while an elliptical-shaped cavity was generated in the backed skin simulant (Fig. 2).

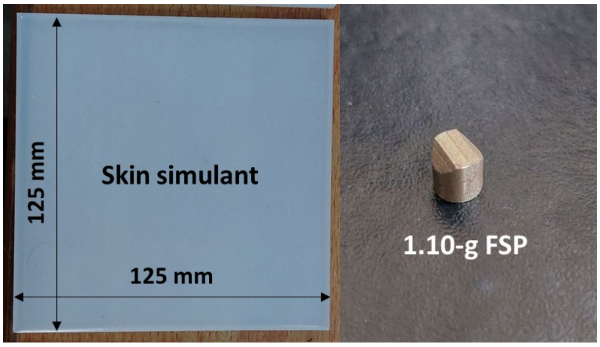

Fig. 1. Photograph of skin simulant and FSP.

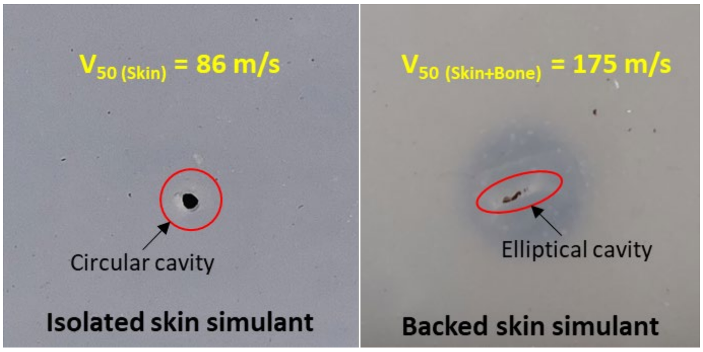

Fig. 2. Cavities generated in isolated and backed skin simulant.

IV. DISCUSSION

The effect of backing material on the ballistic response of skin simulant against 1.10 g chisel-nosed FSP was investigated using a pneumatic gas gun setup. The V_{50} corresponding to only skin simulant perforation in the backed case was not possible because, after partial penetration in the skin simulant, the fragment rebounded due to the presence of bone simulant. Hence, to get the complete perforation in the backed case, V_{50} corresponding to skin and bone simulant perforation was calculated. However, at velocities slightly higher (~10%) than V_{50} of isolated skin simulant, FSP initiated failure of backed skin simulant and created cracks in bone simulant. The V_{50} corresponding to perforation of backed skin and bone simulant was 106% higher than V_{50} corresponding to isolated skin. The results indicate that the backing of skin simulant insignificantly increased the velocity required for failure initiation in skin simulant, but significantly increased V_{50} corresponding to complete perforation (i.e. no rebound), which is consistent with previous literature [2].

The skin simulant failed by shearing a cavity and elastic hole enlargement. When the fragment impacted on the skin simulant, it stretched in the direction of the fragment up to a specific limit. A shear zone was created beneath the fragment face, which subsequently sheared away the skin simulant to form the cavity. The major difference was that shearing was the dominant mode in isolated skin simulant, while elastic hole enlargement assisted by tensile tearing was the dominant mode in backed skin simulant. A circular-shaped plug was ejected from the isolated skin simulant, while a very tiny elliptical plug was seen in the backed skin simulant. This is the reason why the shape of the cavity was different in both cases. A circular cavity was obtained in the isolated skin simulant, while an elliptical-shaped cavity was obtained in the backed skin simulant. In conclusion, the backing of the skin simulant affected the V_{50} as well as its failure. Hence, in assessment of projectile or armor, skin simulant with backing simulant layers depicting the layered arrangement of organ under consideration (e.g., head layers in this case) should be used to get more accurate V_{50} values and failure pattern.

V. REFERENCES

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