THE EFFECT OF COMPOSITE STRUCTURE ON THE BULLET PROTECTION EFFICIENCY

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1. Introduction
Interest and demand on body armor have been increased steadily to protect the body from bullet or shrapnel. The protection panels consisting the body armor are mainly divided into two types: woven type and fiber reinforced composite (FRC) type. Recently composites made out of woven fabric instead of bundle of fibers have drawn attention because the woven type sheets provide better dimensional stability, subtle conformability, and moldability [1~3]. Regardless the type of sheet, they are basically made out of high-tenacity fibers due to their high energy absorption ability [4].

The most important required ability of armor is resistance from penetration of bullets or shrapnel. In addition, personal armor should be light and comfortable [5]. While woven type armors are soft and comfortable, they are known to be inefficient in protecting body from penetration compared to FRC. Therefore, recent researches regarding armor materials are concentrating on the development of armor grade composites [6~10]. The fibers for FRC are traditionally ultra high molecular weight polyethylene (UHMPE) and aramid fibers. However, the consisting materials of FRC are various from carbon nanotube, glass fiber, graphite to polyurethane, epoxy resin.

Over the past decade, considerable amount of efforts have been focused on identifying and elucidating various penetration-failure mechanisms of the armor-grade composites. Fiber reinforced polymer-matrix composites, especially among them drew attention mostly because they are the most advanced commercially available materials. The penetration-failure mechanisms of the fiber reinforced composites carried under transverse impact loading compared with those operating in the related resin-free fabrics [11~13].

Recently, a new type of FRC which is resin-free but the fibers tied into a bundle was introduced as an armor grade composite. However, comparable protection efficiency of a new type resin-free FRC with other commercial materials have not been verified and none of the protection panel made from the new material was yet to be found. In order to investigate the bullet-protection efficiency and impact reducing effect of various armor materials, woven and FRC types including new-type of FRC material were evaluated in this study. In addition, two different types of polymeric films were applied to the woven type material and resin-free FRC fabric to evaluate their effect on the protection efficiency of the protection panel.

2 Materials and Method

2.1 Materials
The materials used in this study include two different types of plane woven Kevlar fabrics (WA, WB) which are made of the para-aramid synthetic fibers, purchased from DuPont Korea. Two types of fiber reinforced composites (FRC) from DuPont were also used. Soft and hard films used for making stack structured samples were made out of polyurethane and imides, respectively.

2.2 Sample Preparation and Fabrication
Each material was cut into a square of 22X22(cm) for testing. Weight and thickness of a single layer for each sample were measured. Protection panels were prepared by stacking the sheets without any adhesion or stitching to eliminate the binding effect. The edge of the prepared panels was inserted between a set of frames and fixed with screws.

2.3 Characterization of the Materials
In order to investigate the relationship between the fabric structure and the efficiency of bullet-protection, the physical properties of the materials used in the experiments were measured. The areal density was calculated from the measured data. Tensile and tear strength were measured by Universal Testing Machine (UTM H100KS). The micro structures of the materials were observed under an optical microscope.

2.4 Bullet Resistance Tests

The antiballistic tests were carried out using a droptester [Fig.1] designed by KITECH. Tests were performed starting from a single layer and proceeded by stacking another layer after layer of the same material until the prepared protective panel resisted from the punctuation by projectile. To investigate the bullet resistance mechanism according to the fabrication structure, the materials with different hardness of polymeric films were stacked to desired configuration. Four different configurations were produced in this way; Composite A = CB+soft film, Composite B = CB+hard film, Composite C = WA+soft film, and Composite D = WA+hard film.

3. Results and Discussion

3.1 Characterization of Used Materials

The characteristic of each material was summarized in Table 1. Most characters of two types of woven materials were similar except areal density and modulus. Although the areal density and tensile strength of WA were slightly higher than WB, the values were not significant. In case of FRCs, two materials showed very distinct properties in all characters. Areal density of CA was a little bit higher than the woven type materials but the tensile strength of CA was low compared to the woven materials [Fig.2]. However, elongation at break and the thickness of CA was considerably low compared to the woven type materials. Another type of FRC, CB was shown to be very thick and strong material. Most characters of CB were 3 times higher than the other materials. However, elongation at break was slightly higher than woven materials.

<table>
<thead>
<tr>
<th>Character /material*</th>
<th>WA</th>
<th>WB</th>
<th>CA</th>
<th>CB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areal density, [g/m²]</td>
<td>180</td>
<td>163</td>
<td>190</td>
<td>500</td>
</tr>
<tr>
<td>Tensile strength, [N]</td>
<td>2280</td>
<td>2092</td>
<td>2015</td>
<td>6570</td>
</tr>
<tr>
<td>Elongation at break, [mm]</td>
<td>4.9</td>
<td>4.08</td>
<td>2.18</td>
<td>5.4</td>
</tr>
<tr>
<td>Thickness, [mm]</td>
<td>0.248</td>
<td>0.247</td>
<td>0.155</td>
<td>0.530</td>
</tr>
</tbody>
</table>

*WA and WB are woven type materials and CA and CB are fiber reinforced composites.

Tear strength of woven type materials was considerably high compared to the composite materials. In case of woven type of materials, specimens were torn apart eventually after 50 to 70 mm extended. The specimen of WB was extended longer than WA before tear. It may be because of the low areal density resulted in loose structure. Composite materials did not have maximum force at tear. However, FRC’s were continuously torn and did not seem to be torn apart within sample size distance. The tearing force of CA was very low. It was almost negligible.
Fig. 2. Tensile strength of used materials

Microscopic views of materials are shown in Fig. 3. Structural difference between WA and WB was not detected. Both materials are plane woven fabrics with similar warp and weft width. In case of FRC materials, constructed fiber bundles were unidirectionally arranged but the fabrication method was dissimilar. For CA, uni-directionally arranged fibers were glued to each other with an adhesive and formed a fine thin sheet. The prepared two thin sheets were cross piled and these piled sheets were thermally sealed with polyethylene film on both sides. Composite B was prepared by gluing two UD sheets. For the CB, the uni-directionally arranged fibers were segregated and tied with polyester yarn.

Fig. 3. Optical microscopic view of fabric structure

3.2 Bullet Protection Efficiency

First of all, a minimum layer of each material for bullet-protection was determined. Although the protection panel prepared with woven materials were thick and heavy, the trauma was severe compared to the FRCs according to the penetration depth in the clay [Fig. 4]. Considering that light weight and thin panel with the least trauma is the most efficient protection panel, CA was the best fit material for bullet-protection.

Fig. 4. Penetration depth in the backing clay for the protection panel composed of homogenous layers

The effect of film covering the panel on the protection efficiency was as the following. The penetration depth of Composite A (CB + soft film) and Composite B (CB + hard film) was reduced by 5mm and 3mm compared to CB alone, respectively. In case of panel with woven material, the depth was reduced by 2mm and 5mm added with soft film and hard film, respectively [Fig. 5].
Fig. 5. Penetration depth in the backing clay for the protection panel composed of homogenous layer and film

4. Conclusion

The results showed that the FRC demonstrated a better bullet resisting performance compared to the woven type materials considering the weight and thickness of stacked samples. Especially FRC with the polymeric film resulted in a significant reduction on depth of trauma. However, the type of polymeric film should be carefully selected to attain efficient bullet resistance property because the protection efficiency differentiated depending on the type of film. It is shown that a soft film improved the protection efficiency significantly of FRC, but a hard film was not as efficient as a soft film. A soft film may contribute by compensating for the lack of FRC in energy absorption. On the other hand, a hard type of film was more proficient on reduction of the impact from shots when the protection material was woven type fabric. It is assumed that the hard film supplements the strength of woven material.

References