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Ballistic Resistance of Plain Woven p-Aramid Fabrics

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Abstract

This research investigated the ballistic resistance of p-Aramid fabric. Plain woven aramid fabrics were prepared to produce bulletproof vest having 5 kg of 32 fabric layers. The performance of the multilayer aramid fabrics in terms of ballistic resistance was evaluated by ballistic testing with the difference types of bullet. The damage of the fabric and the indentation of modeling clay behind the target were examined. The results showed that vests prepared from 18 - 32 fabric layers exhibited the ballistic resistance; the more the fabric layer the more the resistance performance. In addition, the indentation of the modeling clay decreased drastically from 150.2 mm to 23.5 mm. The resistance performance was found dependent on layers of the fabric and bullet type.

Key word: Aramid fabric, Bulletproof vest, Bullet impact, Plain weave

Introduction

Bulletproof vest is a protective clothing which protects the bullets. In designing the bulletproof vest, types of material such as fibres and performance of protection will be considered. Type of ballistic protection clothing could be divided into soft armour and hard armour.[1] The soft armour is made from textile material protecting the wearer from small-caliber handgun and shotgun. In contrast with the soft armour, the hard armour consists of vest reinforced with hard-plate such as metal or ceramic for protecting other weapons.

From the National Institute of Justic Standard[2], the ballistic-resistant body armour is divided into different types. First, for routine wear is available in type I, II-A, while type II will protect from common handgun. Second, type III-A will provide protection from 9mm gun and .44 magnum handguns. Finally, types III and IV will protect against high powered rifles. The working principle of the bulletproof vest made from synthetic fibres was explained in the following.[3-4] When the bullet striked the vest, the fibres in the vest caught the bullet and brought it to a stop. These fibres absorbed and dispersed the impact energy as heat, causing the bullet to deform.

Various materials have been employed for the protection against the ballistics such as polyethylene composite[5], steel[6] , ceramic[4] and synthetic fibres[3, 7-9]. The synthetic fibres which use for ballistic protection are ultra high molecular weight polyethylene and aramid fibres.

Para-aramids are fibres of very high orientation and high strength[10] It was used in safety and protective clothing such as body amour due to good dynamic energy absorption characteristics, high strength and modulus, and excellent thermal properties.[1]

The performance of the bulletproof vest, made from textile fabrics, depended on the inner factor of the bulletproof vest such as fibre type, fibre properties, yarn structure and fabric construction. Also, the outer factor was condition of shooting such as type of bullet, velocity and size of the bullet.[11] Demeski et al. reported that the cross over points of warp and weft yarns of a ballistic fabric were the highest damage from the bullet impact.[5] The ballistic impact of the Kevlar woven fabric impregnated with a colloidal silica was studied by Lu et al. The impregnated fabric exhibited less pullout of yarns. Also, the increasing of the layers of the fabric decreased the penetration depth of modeling clay.[3] Regassa et al. reported that the composite body amour of 20

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layers of the woven Kevlar-29 fibre with polyester resin showed no penetration of bullet impact.[9]

The fabric construction (plain, twill basket and satin) of the Aramid fabric on the bulletproof behavior was reported by Chu and Chen. At low speed test of bullets, the single-layer of plain weave construction showed the best proofing properties. In the hight speed testing, multilayer construction of basket fabric had the highest resistance, followed by the plain weave construction. The fabric construction was the important factor to stop the bullet. The fibres in the vest should be packed tightly.[11]

Hence, it is interesting to study the bullet resistance of textile fabrics. In this study the p-aramid spun yarns was woven into plain fabric. The ballistic resistance of the aramid fabric was examined. The ballistic resistance performance was evaluated based on two factors (bullet type and fabric layers). In this study, up to 32 fabric layers were constructed to produce the bulletproof vest. The bullets used were 9 mm, .357 magnum and .44 magnum.

Materials and Experimental Procedure

Materials

p-Aramid spun yarns purchased from Crosstex Co., Ltd (Thailand).

Measurement of tensile properties of yarn

Tensile properties of p-aramid spun yarns were measured according to the ASTM D2101-93 standard test method using an Universal Testing Machine (Hounsfield H10KM, U.S.A.) The cross head speed used was 300 mm/min. 12 samples were used for measurement; using the gauge length 200 mm and the average values were reported.

Production of Aramid fabrics

The p-aramid spun yarn was weaved to plain woven fabric construction.

Measurement of weight of aramid fabrics

The weight of the aramid fabrics were measured by using balance. Measurement were made from the sample, having the size 40×40 cm.

Production of bulletproof vest

The 32 layers of the aramid fabric were cut to form the bulletproof vest covered with the black polyester fabric. The vest size was shown in Table 1.

Table 1 Size of bulletproof vest

Measurement	Size (cm)
Chest	112
Neck size	42
Sleeve	89
Waist	97

Ballistic tests

The woven fabric (18-30 layers) or the bulletproof vest (32 layers of the aramid fabric) were impacted with the bullet at distance 5 meter. A thick block of modeling clay in wooden mold (15.24 cm × 8.89 cm × 8.89 cm) were placed behind the fabric and clamped together with the elastic tape as shown in Figure 1. For estimation of the bullet impact on the target, an indentation on the surface of the modeling clay was measured as shown in Figure 2.

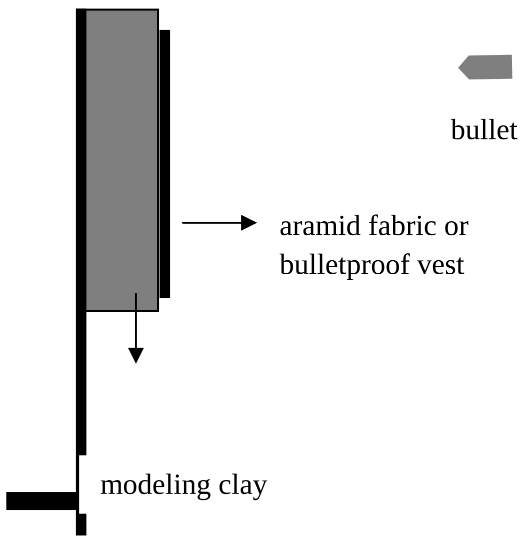

Figure 1 Schematic diagram of the ballistic test.

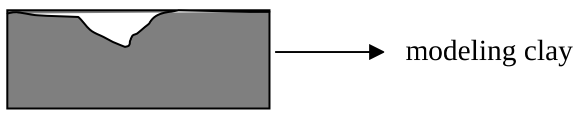

Figure 2 Schematic diagram of the indentation of modeling clay behind the target after bullet impact.

Results and Discussion

Tensile properties of aramid yarns

The tensile strength and elongation of the aramid yarns are shown in Table 2. The result showed that this material had low elongation but high strength. Thus, this yarn was suitable for weaving into fabric.

Table 2 Strength and elongation of p-aramid yarn

Properties	Value
Tensile strength	208.5 N
Tensile elongation	35.5 mm

Weaving of the aramid fabric

The aramid fabric was weaved to plain weave construction. Plain weave is the simple weave. The weft yarns pass over and under alternative warp yarns. This is the maximum amount of interlacing possible in a woven fabric. Thus the fabric is strong and durable.

Specification of the aramid fabric is shown below.

$$\text{width of fabric} \; \frac{\text{warp yarn} \times \text{weft yarn}}{\text{number of warp yarn} \times \text{number of weft yarn}}$$

$$48 \; \frac{10/2 \times 10/2}{30 \times 30}$$

This data showed that the width of the woven fabric was 48 inch (121.92 cm). This fabric consisted of warp yarn number 10/2 with 30 yarns / inch and weft yarn, also, number 10/2 with 30 yarns / inch.

The weight of the aramid fabric was 550 g/m^2. The result showed that it had the heigh weight. For production of the billetproof vest, it indicated that the used of the aramid fabric caused the heavy weight of the vest. This resulted from the construction of the fabric.

Ballistic test of aramid fabrics

For testing of the ballistic, the target (aramid fabrics) composed of 18-30 layers of the fabric. The result of the testing are shown in Table 3 and Figure 3-4. The resistant characteristic of the aramid fabric from the bullet impact was evaluated from the fabric destruction and an indentation of the modeling clay.

Table 3 Ballistic performance of aramid fabric with the difference layers

Level of NIJ ballistic protection	Type of bullet	Layers of fabric	Impact velocity (m/s)	Penetration depth (mm)
IIA	.357 magnum	18	352	150.2
		24	358	23.1
II	9 mm	24	436	32.4
IIIA	.44 magnum	24	453	36.1
		30	450	31.4
		30	452	32.9

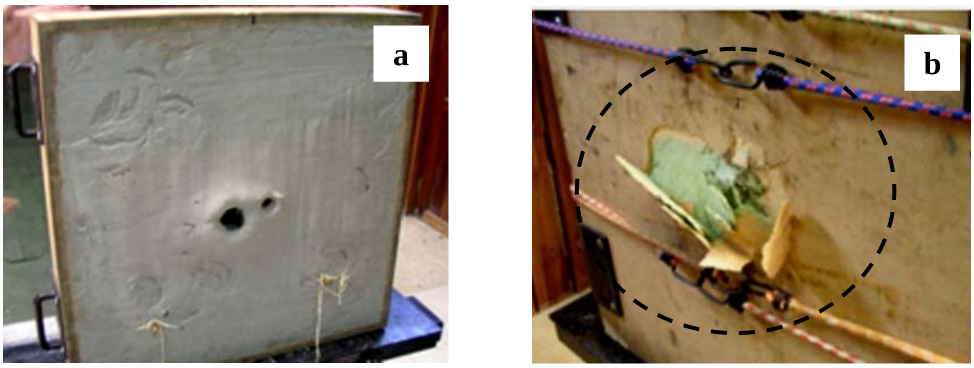

Figure 3 Testing of aramid fabric with .357 magnum: (a) penetration of the bullet at the front of the modeling clay and (b) the thrown off at the back of the modeling clay box.

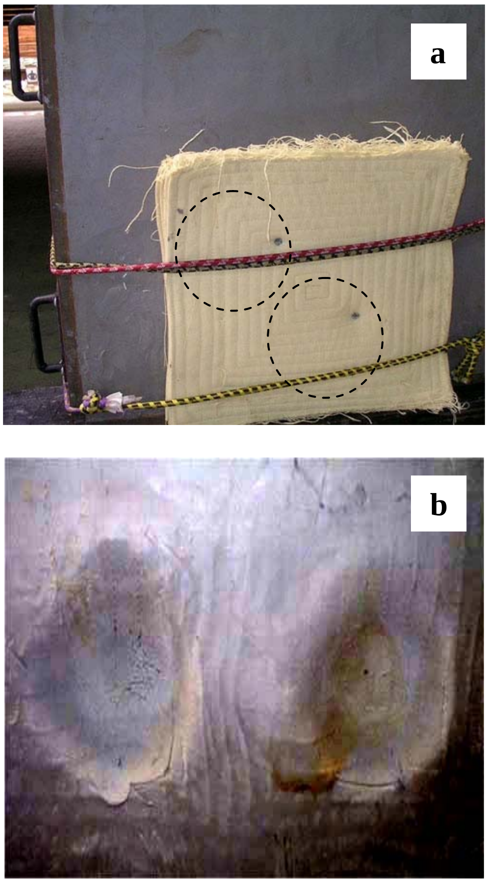

Figure 4 Testing of 30 layers of aramid fabric with .44 magnum: (a) stop of the bullet in the Kevlar and (b) indentation of the modeling clay at the back of the aramid fabric.

At the condition of the .357 magnum and 18 layers of the aramid fabric, the bullet passed through the panel (see Figure 3 (a)) and caused the material to be thrown off at the back of the panel as shown in Figure 3 (b). Hence, the 18 layers of the aramid fabric were not sufficient to protect the impact from the bullet.

For the same type of the bullet, the result showed that the increasing the layers of the aramid fabric increased the resistance of the bullet penetration (see Table 3). Also, the indentation of the modeling clay decreased. This indicated that the performance of the aramid fabric from the impact increased. However, for 24 layers with the different types of the bullet, the increasing the velocity of the bullet increased the indentation of the modeling clay (see Table 3). This resulted from the high energy of the high velocity of the bullet impact. Thus, for increasing the level of protection, the layers of the fabric should be increased.

The failure of the fabric by the bullet impact was described in the following [1, 7]. The absorption of the energy by the fabric was occurred during the bullet impact. Also, the energy was transferred to the yarns. This caused the defect of the fabric after impact by the bullet. For the thick layer of the fabrics, the dissipation of the energy was likely provided by the first layer of the aramid fabrics. This resulted in the indentation of the modeling clay and the stop of the bullet as shown in Figure 4.

Ballistic test of bulletproof vest

For cutting the bulletproof vest, the 32 layers of aramid fabric was used. The vest was designed for realistic testing. The bulletproof vest product with the weight of 5 kg was shown in Figure 5. In general, the bulletproof vest must be light weight. From the National Institute of Justic (NIJ) (U.S Department of Justice) [2], the Kevlar bulletproof vest must have a minimum 4 pound (1.81 kg) in order to give good protection.

Figure 5 Characteristic of bulletproof vest.

For testing of the bulletproof vest from the bullet impact, the vest was tested under .44 magnum at the front size and back size of the vest. The result is shown in Table 4 and Figure 6.

Table 4 Ballistic performance of the bulletproof vest produced from aramid fabrics

Position of Panel	Times of shooting	Impact velocity (m/s)	Penetration depth (mm)
Front	1	456	26.9
	2	445	23.8
	3	451	25.4
	4	447	23.8
	5	452	27.0
Back	1	443	23.5
	2	450	26.8
	3	454	25.0
	4	452	29.0
	5	453	24.7

Figure 6 Testing of bulletproof vest from bullet impact: (a) clamping the vest with modeling clay; (b) indentation of modeling clay after the bullet impact on the vest (front size); (c) bullet blocked in the front size of the vest and (d) bullet blocked in the back size of the vest.

The result showed that it appeared a small indentation in the range from 23.5 to 29.0 mm on the surface of the modeling clay as shown in Figure 6 (b). From the National Institute of Justic (NIJ) (U.S Department of Justice)(2), the indentation of the modeling clay should not exceeded 44 mm in the quality testing of the bulletproof vest. The damage of the fabric in the vest was not much, also, the bullet was blocked in the fabric as shown in Figure 6 (c-d). Hence, this result indicated that the plain weave of the aramid fabric had the performance to resist the bullet. Chu and Chen reported that the plain weave construction had a high density of warp-weft interweaves(11). This caused the fabric resisted the impact. However, the weight of the bulletproof vest should be reduced for the comfortable to wear.

Conclusion

The plain weave construction of the aramid fabric was designed to produce the bulletproof vest. The resistance of the aramid fabric from the bullet impact depended on the layers of the fabric, impact velocity and type of bullet. The bulletproof vest consisted of the 32 layers of plain weave aramid fabric had the performance to resist with the .44 magnum.

Acknowledgement

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