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Research Article

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Study on the Arrangement of Fabric Materials for Multi-Layer Soft Body Armor Based on their Mechanical Properties

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Abstract

The arrangement of protective material of bullet proof vest is important for face and back strike when all backing materials are hybrid. In this paper, three hybrid protective materials, as UD aramid fabric, Polyethylene (PE) and laminated woven aramid fabric (Argus) were used in this work. The bullet proof vest made of these combinations of materials to wear flexible and comfortable. It was found that the mechanical properties, as work of rupture of material, Young's modulus, bursting strength and penetration stroke at bursting, give trend to arrange the face and back strike for bullet proof vest, the increasing of work of rupture enables energy-absorbing mechanisms and the materials with high work of rupture enable to absorb energy to predict the arrangement of the layers before shooting.

Keywords

Aramid fabric; Soft body armor; Mechanical testing; Ballistic protection

Introduction

The main purpose of bullet proof vest is to provide good ballistic and edged weapons protection for vital organs such as heart, lungs, liver, kidneys, spleen and backbone. Ballistic personal body armor is designed to protect against behind armor blunt trauma, including back - face signature injuries.

The extent of these injuries can range between mild grazing to organ damage and, in extreme cases, even death. Studies of wounded police officers have shown that bulletproof vests saved hundreds of lives each year.

A back-face signature injury occurs when the body armor retains the round, but does not effectively dissipate the energy efficiently, causing a narrow section of the armor to deform backward into the body, penetrating the skin and causing an injury.

To assemble bullet proof vest, it is very important that the manufacture inserts the ballistic panels into the carrier in the correct direction of strike face and back face. The arrangement of layers of protective materials is very specific task, it must be considered during manufacturing. Improper insertion of a ballistic panel can result in serious injury or death. The proper orientation of the ballistic panel in the carrier must be clearly identified for strike and back face for soft body armor. The strike face is the side of the armor panel intended to be hit by the bullets. When used multi materials as backing for the body armor, the problem is which material will be as strike face and which will be as back face. In this article, depending on the mechanical properties of protective materials, three different hybrid materials could be arranged as strike and back face.

Fiber reinforced polymer composites have been widely used for protective structures, particularly those with high-performance fibers [1]. When polymers are intended to be used for lightweight ballistic protection or soft armor, weak fiber matrix adhesion is required to allow the fibers maximum deformation [2], thus absorbing more impact energy.

U.S. Patent No. 4,584,228 [3] describes a bulletproof garment including several layers of textile fabric or foil superimposed on a shock absorber, in which the shock absorber is a three dimensional fabric with waffle like surfaces, a hollow part of at least 90% by volume and a thickness of 5 to 30 mm. Such fabrics are distinguished by good pressure resistance and make possible a good conversion of energy.

In the case of thermoplastic polymers have an advantage over thermosetting matrices, which are known for their high stiffness and low deformation [1,4]. It has been shown that by adding limited amounts of thermoplastic resin to the fabric, an improvement in the impact resistance can be obtained [5] because the thermoplastic matrix maintains the orientation and position of the fibers during an impact event and distributes the load caused by the impact among the fibers [1].

In laminate composites the matrix enables delaminating and de-bonding, which are energy absorbing mechanisms [6,7]. The matrix may also protect the fibers from environmental factors such as the reduction of impact resistance under conditions of high humidity [8] and the reduction of mechanical properties due to photo degradation caused by ultraviolet radiation [9,10].

One of the most widely known polymer fibers for protective systems is the aramid fiber can be found under the trade name of Kevlar [5]. Fabrics made of this aramid fiber have high strength, high modulus and good tenacity, which are desirable properties for ballistic applications; however, they are relatively expensive [5] and the design of protective equipment with these fabrics should include studies to reduce the amount of required fabric layers without compromising the effectiveness of the armor.

In the area of research for protective materials, the standard laboratories are not available to evaluate soft body armor, it is very costly and limited worldwide. Additionally, evaluation of body armor is quite time consuming and not feasible in many countries. Ballistic test requires licenses and permissions from the official authorities to use the shooting field to evaluate anti bullet materials, so the mechanical properties of protective materials are alternative method to evaluate materials of soft body armor, it was found that the results of ballistic test matched with the mechanical properties.

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Experimental

In order to improve antiballistic performance, some means is needed to stop bullet shot gradually according to absorption its energy through combination of different materials with different properties of elasticity. The combination from polyethylene and aramid is in a manner that is reinforcing and aids in the deceleration of the projectile, then an enhanced lightweight protective ballistic armor can be formed.

The choice of the raw materials is not based on the trade famous name of raw materials in the market, but based on the best mechanical properties that achieve high efficiency for body armor during end use.

Materials

The main materials used in this study:

A. UD aramid fabric bonded with stitches.

B. Woven aramid fabric, encapsulated in a thermoplastic coated sheet (laminated fabric).

C. Ultra High Molecular Weight Polyethylene (UHMWPE).

Figure 1 shows the protective materials of body armor comprising three UD aramid, UHMW Polyethylene and woven aramid in sheet shape

UD aramid fabric: It is shown in Figure 1A, which was treated with nanotechnology to offer enhanced bullet stopping power and reduced back face deformation even in our hot climates. UD aramid fabric was woven in diagonal orientation with two layers of fibers.

Aramid sheet fabric (Argus): It is shown in Figure 1B, that aramid fabric sheet, which was unaffected by moisture, humidity or perspiration, because it is water proof. Aramid sheet is a fabric woven of plain weave 1/1 with 26×26 yarns per inch for warp and weft, the warp and weft count 800 diner. Figure 1B shows fabric of Argus aramid sheet, encapsulated in a thermoplastic coated

UD UHMWPE fabric: It is shown in Figure 1C, which made as a unidirectional construction based on ultrahigh performance polyethylene fiber, in which the fibers are not woven but lie parallel to each other. Ultra high performance polyethylene fiber, also called ultrahigh molecular weight polyethylene fiber, is characterized by its extremely super high tenacity and high modulus, so it has various merits of soft, light, corrosion resistant, impact absorption, and high energy absorption. Polyethylene was treated with nanocomposite material to manufacture as an ultrahigh molecular weight polyethylene (UHMWPE). This treatment with nanocomposite improved ballistic properties for polyethylene and is reflected in significant reduction in the projectile velocity as determined by ballistic test.

Mechanical testing

Tensile strength at break: Tensile strength is still the main test to evaluate the quality of textile materials, all three fabrics were tested to tensile strength at break. All tests of breaking strength were carried out in standard laboratory. Test standard ASTM D 5035 [11] was applied for breaking strength. Tensile strength at break of protective textile material is measured by applying a tensile force parallel to the plane of the textile material and great enough to induce failure or rupture. In this way we get the breaking strength to compare different materials to their inherent strength. Five samples from all materials were tested and the average was calculated.

Bursting strength (ball burst test - puncture assembly): Bursting strength is a complicated function of tensile strength and stretch, combination these different aspects of tensile behavior together in a confusing way. This test was used as simulation to evaluate the protective materials to predict the behavior and quality during shooting. The test of bursting will simulate the required force could be borne be a single layer of material till bursting and also the maximum distance of ball penetration inside material. The test result of bursting may help to compare and evaluate the material to choose the best of them as arrangement and number of layers.

Test standard ASTM D 3787 [12] was applied for bursting strength, with constant rate of extension (CRE) ball burst test with puncture attachment assembly. At least five samples for each material was tested and the average was calculated. All tests were carried out in standard laboratory in Germany.

Results and Discussions

Behaviour of the materials at tensile strength

Figure 2 shows the behaviour of one sample for three protective materials during tensile testing, at the same time, the textile material elongates under the influence of this tensile force. It is clear that work is being done on the specimen. The work done up to the instant of tensile failure is called the "work of rupture" and it as measured or calculated as the area under the curve for every samples. It is noticed from Figure 2 there are variation and difference of tensile strength and elongation for samples.

Breaking strength for samples as follows, UD aramid 291 kg, aramid sheet Argus, 870 kg, and UHWM polyethylene was 1006 kg, and elongation for samples, as follows, UD aramid 44.6%, aramid sheet Argus.5.6 %, and UHWM polyethylene 8%.

The protective materials could not be evaluated by tensile and elongation only, but by work of rupture which is a function of tensile strength and elongation together and also Young's modulus to evaluate the performance of protective materials when exposed to shooting to absorb it.

Work of rupture and energy absorption

It is one of the results that can obtained from the test tensile strength at break and it can be calculated as the area under the curve, but most of software program of tensile test can calculated it directly.

Figure 3 shows work of three materials. Its value for aramid sheet was 20.31 Joule, work of rupture for UD polyethylene material was 27.69 Joule, and work of rupture for UD aramid fabric 28.58 Joule. The energy absorption can be calculated as the ratio of work of rupture over the area of sample.

Because of all samples have the same area, and then the energy absorption is directly proportional to work of rupture, then the protective material which has high work of rupture, it will have also high energy absorption may help to absorb the sudden shock of bullet, and return back flexibility, so it must be placed at the first group of first layers as strike face. By comparing work of rupture for the three materials, it was found that work of rupture of UHMWPE achieved the second place after UD aramid; it means that this material also can absorb and distribute the energy of bullet, so it can arranged in the second group of layers of body armor.

By comparing work of rupture for the three materials, it was found that work of rupture of aramid sheet fabric achieved the third

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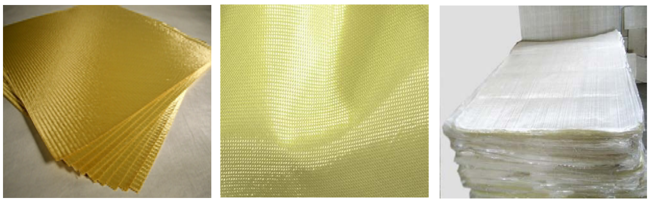

(A) UD aramid fabric (B) Aramid fabric (Argus) (C) UD UHMWPE

Figure 1: Materials used for the experiments.

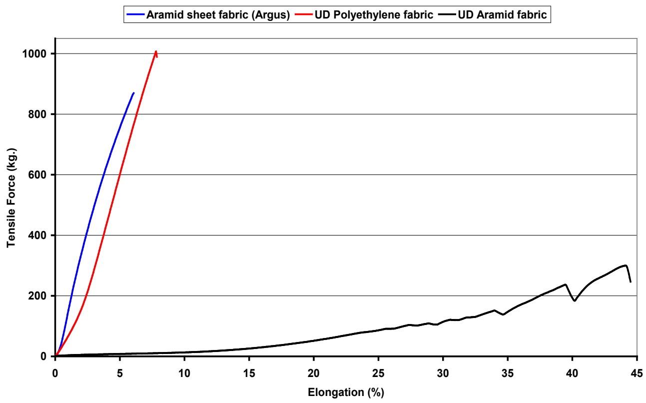

Figure 2: Tensile Force/Elongation curves for aramid sheet fabric, UD polyethylene and UD aramid fabric.

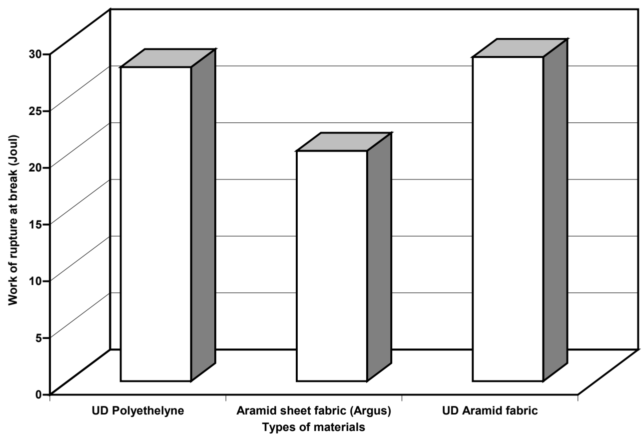

Figure 3: Work of rupture of aramid sheet fabric, UD polyethylene and UD aramid fabric.

place after UD aramid and UMHWPE, it means that this material must arranged in the third group of layers of body armor to stop the bullet and reduce the blunt and to be back face.

E – Modulus: Young's modulus

To confirm that the mechanical properties of protective materials can predict the performance and arrangement of soft body armor, E modulus was discussed for this purpose. It is also one of the results from the test of tensile strength at break and it can be calculated or obtained directly from software program of tensile test.

E – Modulus: Young's modulus measures the resistance of a material to elastic deformation under load. A stiff material has a high Young's modulus and changes its shape only slightly under elastic loads. A Flexible material has a low Young's modulus and changes its shape considerably.

From the results of the three protective materials, it was found that E-modulus of UD aramid was 3.61 GPa, E-modulus of UHMWPE was 59.15 GPa, and E-modulus of aramid sheet was 69.71 GPa.

From these results, the UD aramid fabric has the lowest E-modulus, it means it is very elasticity to absorb the energy of bullet, so UD aramid must be as strike face, but the aramid sheet fabric has the highest E-modulus, it means that it is very stiff, the ballet can go through and penetrates it, so it must be at back face to reduce the trauma of ballet. UHMWPE fabric can inserted between UD aramid and aramid sheet fabric (Argus), E-modulus of UHMWPE fabric is lower than aramid sheet fabric (Argus) which helps to distribute the energy of ballet (Figure 4).

Bursting test's results

Figure 5 shows the behaviour of one sample as a guide for three protective materials during testing of bursting strength. During bursting test the puncture force applied on protective material to simulate the same effect of bullet approximately, and the penetration is steadily increased, at the same time till failure.

Figures 6 and 7 show that bursting strength of UD aramid was 322 kg and penetration stroke within this material 66 mm till failure. It means that this material has the ability to absorb the sudden shock from the bullet, and penetrate back certain distance to absorb energy of bullet, so this material can be arranged as strike face confirmed the results of the work of rupture and E-Modulus. Figures 6 and 7 show also bursting strength of UHMWPE 229 kg and penetration within material about 45 mm, It means that this material has the ability to absorb the sudden shock from the bullet, and penetrate back certain distance to stop the bullet, but its flexibility ranked after UD aramid, so this material can be arranged after UD aramid fabric of body armor.

For aramid sheet fabric Figures 6 and 7 show that bursting strength was 360 kg, and penetration stroke within material about 27 mm only, it means that this material is very stiff, when arranged as first layer, it must be penetrated very easy. This material has the ability to stop the bullet after recharge its energy through absorption from the two other materials, so this material must be arranged as third layers of body armor to reduce the blunt trauma as minimum.

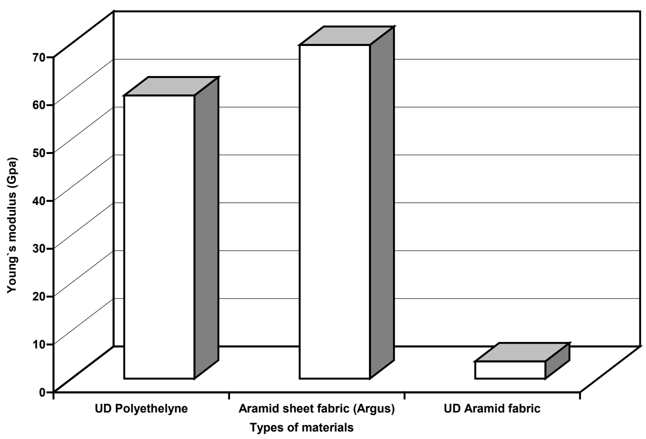

Figure 4: Young's modulus of aramid sheet fabric, UD polyethylene and UD aramid fabric.

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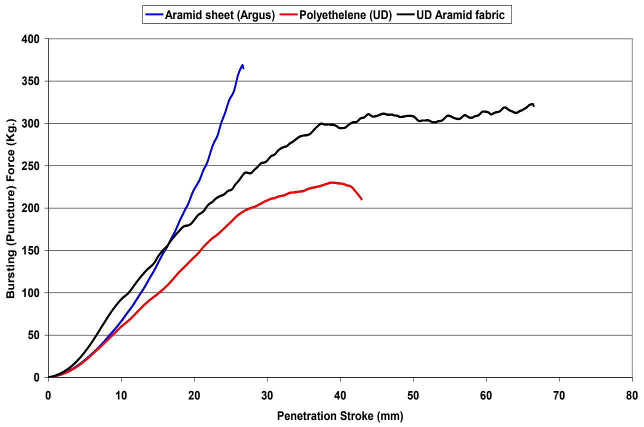

Figure 5: Bursting force/penetration stroke curves foraramid sheet fabric, UD polyethylene and UD aramid fabric.

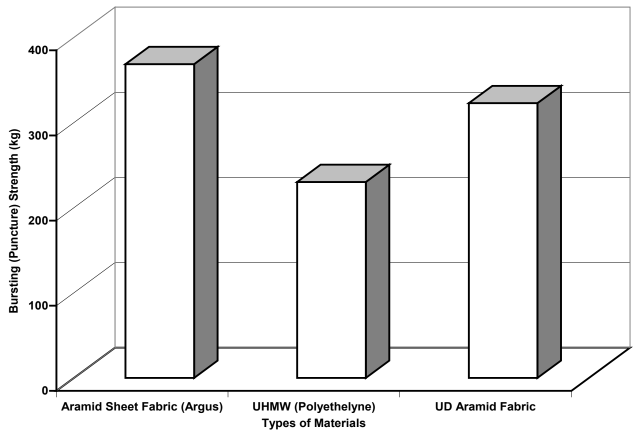

Figure 6: Bursting strength of aramid sheet fabric, UD polyethylene and UD aramid fabric.

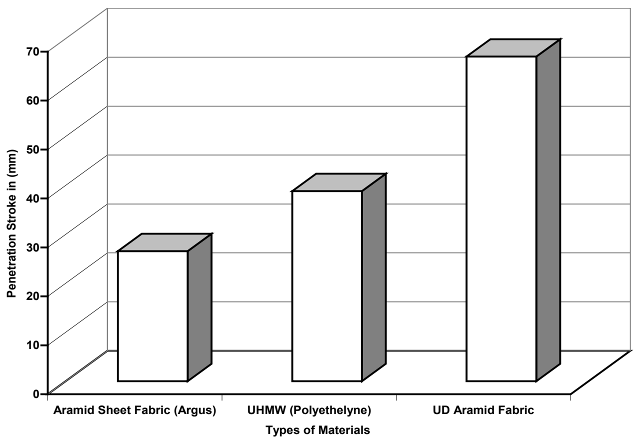

Figure 7: Penetration stroke of aramid sheet fabric, UD polyethylene and UD aramid fabric.

Ballistic test

From mechanical properties as work of rupture, E-modulus penetration stroke, the total layers of protective materials were twenty four, and arranged as selected six layers of UD aramid fabric at the front of body armor to be strike face, depending on its mechanical properties which helps to absorb shock, followed by twelve polyethylene fabric to absorb the rest of shock and to reduce the blunt into the body, and third group six layers were from aramid sheet used as back face to reduce the trauma. The three protective material with suitable layers were arranges as shown in Figure 8 to produce complete body armor and test on shooting field.

The resistance of bullet proof vest, not only depends on the properties of individual protective materials, but also depends on the properties of all hybrids protective materials together, in this case the differences between E-modulus of UHMWPE and E-modulus of aramid sheet was not significant.

Figures 9 and 10 show the test of shooting with five bullets was carried in shooting field for military, prepared with all required equipments for 0101.04 NIJ standard [13] using these tools, type of handgun bullets MP5, bullet diameter 9 mm, bullet mass 8 gram, speed of bullet 427 m/s, and distance of shooting five meters. The results of shooting showed, that number of penetration layers were only six, no sign penetration of bullet, the clay dummy had no holes or pieces of vest or bullet in it and the trauma was 22 mm to pass as specifications of 0101.04 NIJ standard.

Conclusions

The arrangement of protective material of bullet proof vest is very important for face and back strike when backing materials of soft body armor are from different three raw materials.

Mechanical testing as tensile strength and bursting strength are low cost tools to predict the behaviour of backing protective material and its arrangement as strike and back face before production.

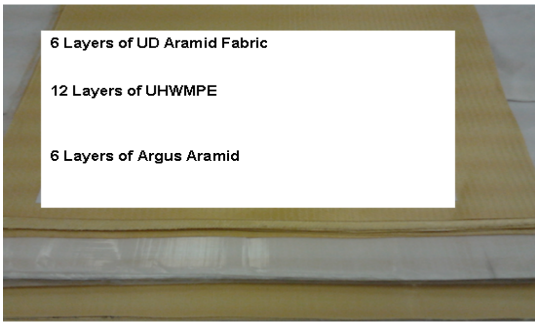

Figure 8: The arrangement layers of protective fabrics of bullet proof vest depending on mechanical properties.

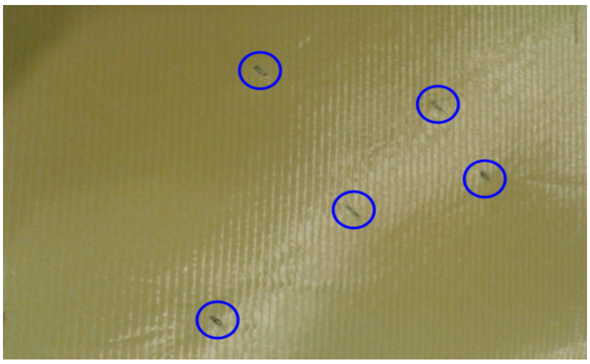

Figure 9: Results of the ballistic test.

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Figure 10: Bullet penetrates six layers of UD aramid and stop, 0101.04 NIJ standards.

Mechanical properties as work of rupture of material, Young's modulus, bursting strength, give trend to arrange the face and back strike for bullet proof vest to get high performance for the body armor at end use

By use of new material finished with nanotechnology to improve performance of through the ideal arrangement of different material of body armor.

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