# Stab Resisting Behavior of Polymeric Resin Reinforced *p*-Aramid Fabrics

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**ABSTRACT:** The stab resistant performance of *p*-aramid fabrics reinforced with thermoplastic LDPE resin and thermoset epoxy resin was investigated by quasi-static or drop tower stab resistance testing, and the stab resistance behavior against different shapes of impactors was also evaluated. The destruction behavior of LDPE reinforced *p*-aramid fabrics against a knife impactor shows three distinctive steps; the initial penetration step with maximum strength, the cutting step by knife edge, and the destruction step of accumulated fiber bundles. On the other hand, epoxy resin reinforced *p*-aramid fabrics against a knife impactor exhibit just two steps without the accumulation of fiber bundles. In the case of a spike impactor, the maximum stab resistant strength is observed from the initial penetration step; however, the stab resistant strength after initial penetration drastically decreased regardless of the reinforcing resins. It is also found that, even if the LDPE reinforced fabrics are multilayered, the performance improvement by resin reinforcement is observed only from the initial penetration step and the stab resistant strengths of the cutting step and the fiber accumulation step are not improved. © 2011 Wiley Periodicals, Inc. J Appl Polym Sci 123: 2733–2742, 2012

**Key words:** stab resistance; body armor; stab resistant behavior; quasi-static test; drop tower test

## INTRODUCTION

The development of protective gear has made great progress in many fields such as flame and heat resistant clothes, cut resistant gloves, stab resistant clothes, bullet proof vests, and biological/chemical protective clothes. Among these protective gear, stab protection gear is designed for minimizing human injury from aggressive action by knife, sharp spike, broken glass, and needle. A more advanced stab protection gear has been demanded by governmental and civilian police forces in Europe and Asia where the possession of guns is heavily restricted, thus resulting in an increase of assault committed with knives and sharp objects.[1,2]

Stab resistant materials are fundamentally performing the same function of bullet proof materials in the sense of protecting the human body from harmful projectiles. Stab resistant behavior seems to be very similar to bullet proof behavior. However, stab resistant behavior has a much more complex mechanism than the protection behavior against bullets. Beside the basically dissimilar structure and size of objects used in both types, the kinetic impact energy of the objects to be stopped is fundamentally different.[3,4] While a bullet with a mass of a few grams impacts the target at a very high velocity, the typical terminal velocity of a knife attack is relatively low with a mass of up to several hundred kilograms. Stabbing objects also usually have a sharp edge and a point. This leads to a difference of impact behavior, that is, the sharp edge and point of knife facilitates penetration; however, a bullet is actually flattened on impact leading a larger impact surface area.[5,6] Therefore, stab resistant materials should simultaneously be able to stop penetration by sharp point and cutting by blade edge.

A number of stab resistant materials[7–10] are commercially available. Metal ring meshes are traditionally used for cut protection in food industries such as meat processing, and have been incorporated into some stab resistant vests. These meshes, however, do not provide puncture resistance. Other rigid armor utilizing rigid metal, ceramic, or composite plates can offer excellent stab protection; however, are bulky and inflexible, making them uncomfortable to wear. The utilization of high performance organic fibers such as *p*-aramid, ultra high molecular weight polyethylene (UHWMPE), or polyphenylenebenzobisoxazole etc., provides promising results because these fibers have high tenacity and high tensile modulus due to their highly oriented and rigid molecular structure. Although woven fabrics

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TABLE I
**Specification of the *p*-Aramid Fabric**

| | |
|---|---|
| Yarn count (yarns/in) [wrap/weft] | 17/17 |
| Weave type | 1 × 1 Plain |
| Area density (g/m$^2$) | 435 |
| Thickness (mm) | 0.571 |
| Density (d) | 1500 |
| Tensile strength (kN) [wrap/weft] | 2.1/2.0 |

using these fibers can provide outstanding ballistic resistance, these fabrics alone in general exhibit poor stab resistance due to the sharp and pointy shape of impacting projectiles. One counter measure for overcoming this matter is to incorporate polymer coatings or laminated films into woven fabrics. The polymer matrix provides additional toughness to the woven fabrics, requiring more energy to cut and tear fibers and yarns. Flambard and Polo[6] characterized the stab resistance of knitted fabrics utilizing a nonstandard and undamped drop mass system. Mayo et al.[11] performed the stab characterization studies on thermoplastic impregnated aramid fabrics. Gadow and von Niesen[12] found that a thermally sprayed ceramic coating increased the penetration resistance of a woven aramid fabric against a knife. Many attempts to strengthen aramid fabrics with shear thickening fluid were also reported.[1,13,14]

However, despite the presence of commercially available stab resistant fabrics, previous researches on stab resistant materials have been mainly focused on performance improvement without in-depth understanding of stab resistance behavior. Therefore, in this article, the stab resistant behaviors of thermoplastic or thermoset resin reinforced *p*-aramid fabrics are investigated to understand the effect of reinforcing resins. Concurrently, it is expected that the evaluation of stab resistant performance and behavior of these materials can provide a useful measure for the design and optimization of stab resistant fabrics with flexibility.

## EXPERIMENTAL

### Materials

The fabric used in this study was *p*-aramid (Heracron® provided from KOLON Ind.) with 17 × 17 yarns per square inch of 1500 denier. Detailed specifications for the fabric are given in Table I. Low density polyethylene (LDPE; LUTENE FP0800) film as a thermoplastic reinforcement was obtained from LG Chem. The thickness of the film is 0.068 mm and the area density is 61.4 g/m$^2$. Bisphenol-F type epoxy resin (Bakelite EPR 161, epoxy equivalent weight = 170 ± 10 g/eq, Hexion) was used as a thermoset reinforcement. The curing agent for epoxy resin was aliphatic amine derivative (PEA D230, active hydrogen equivalent weight = 60 g/eq., Hexion).

### Preparation of stab resisting fabric

The LDPE reinforced *p*-aramid fabrics were prepared by using a hot press. A 0.25 m × 0.25 m *p*-aramid fabric with the required thermoplastic films was placed between two teflon sheets and heated with a hot press for 12 min at 160°C and 500 KPa.

The epoxy reinforced *p*-aramid fabrics with different resin contents were prepared by the solvent impregnation process to control the resin contents and to get a better penetration of the resin. The desired amount of epoxy resin and aliphatic amine curing agent based on the calculation of eq. (1) was diluted with acetone to reduce the viscosity.

$$\text{Amount of curing agent (phr)} = \frac{\text{Active hydrogen equivalent weight}}{\text{Epoxy equivalent weight}} \times 100 \quad (1)$$

Then a 0.25 m × 0.25 m *p*-aramid fabric was impregnated in the prepared epoxy/acetone solution and dried in the vacuum oven for 1 h at room temperature. Precuring of epoxy resin was carried out with a hot press for 20 min at 120°C and 500 KPa. Precured epoxy reinforced *p*-aramid fabric was further cured at room temperature for 1 week. Table II gives the sample codes and resin add-ons for the prepared samples.

### Quasi-static stab resistance testing

Quasi-static stab resistance testing of the neat *p*-aramid and resin reinforced fabrics was performed using a Universal Testing Machine (Instron, Series IX automated material testing system). The knife and spike impactors were mounted in the upper grip, and a single sheet of the target fabric was tightly placed below the impactor using a

TABLE II
**Sample Preparation**

| Applied resin | Sample code | Base fabric | Resin add-on (wt %) | Thickness (mm) | Remarks |
|---|---|---|---|---|---|
| LDPE (thermoplastic) | PES1 | *p*-Aramid | 12.4 | 0.58 | One side |
| | PES2 | | 24.8 | 0.69 | |
| | PEB2 | | 24.8 | 0.62 | Both side |
| Epoxy (thermoset) | Ep1 | | 0.1 | 0.63 | |
| | Ep2 | | 2.5 | 0.63 | |
| | Ep3 | | 7.0 | 0.65 | |
| | Ep4 | | 12.2 | 0.65 | |
| | Ep5 | | 26.4 | 0.64 | |
| | Ep6 | | 42.7 | 0.61 | |
| | Ep7 | | 45.5 | 0.63 | |

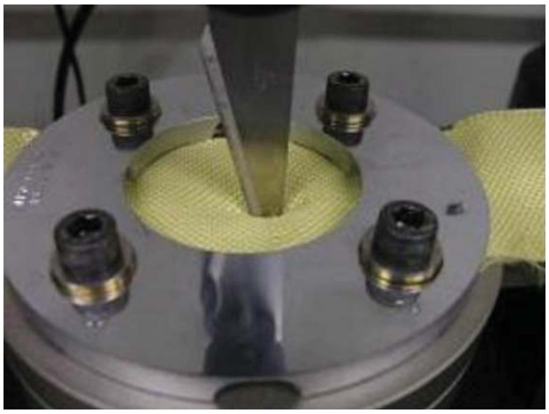


**Figure 1** Custom-made sample holder for the quasi-static stab resistance testing. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

compression jig (Fig. 1). The impactor was then pushed into the target at a rate of 10 mm/min to a total displacement of 50 mm. The penetration angle of the knife impactor to the warp/weft structure of fabric was 45°. Load versus displacement data was recorded using a 1 kN load cell. The single edge blade (abbreviated as P1, BVL-31P model, NT incorporated, Japan) was used as a knife impactor and the custom made spike according to NIJ standard 0115.00[15] was used as a spike impactor (Fig. 2).

### Drop tower stab resistance testing

The stab tests performed were based on the NIJ Standard 0115.00[15] and NIJ Guide 100-01[16] for stab resistance of body armor. For stab testing, 20 layers of stab targets were placed on a multilayer foam backing as specified by the NIJ standard. This backing consists of six layers of 6.0-mm thick neoprene sponge (GLC, Korea), followed by one layer of 31-mm thick polyethylene foam (GLC, Korea), backed by two 6.4-mm thick layers of rubber (GLC, Korea). The witness papers were placed between each layer of neoprene sponge (Fig. 3). The command knife type double edge blade (abbreviated as S1) and spike were used as impactors for the drop tower testing in accordance with NIJ standard (Fig. 2). To perform a stab test, the impactor was mounted to the drop mass in a rail-guided drop tower, and the crosshead was dropped from a fixed height to impact the target. To set the "E1" strike energy which is described in NIJ standard, the total drop mass including impactor was fixed to 1.8 kg and the drop height was adjusted to 1.36 m. The depth of penetration into the target is quantified by the displacement sensor.

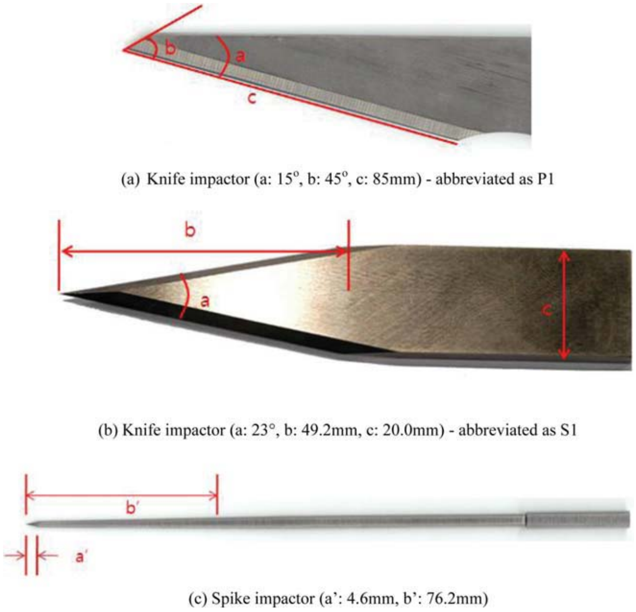



**Figure 2** Specifications of the impactors for stab resistance testing. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

### Imaging of fabric damage

To provide further insights for the stab resisting behaviors, scanning electron microscopy (SEM; JEOL JSM-5510) images of fabric targets after quasi-static testing were obtained.

## RESULTS AND DISCUSSION

### Appearance of stab resistant *p*-aramid fabrics

Since stab resistant materials composed with textile structure have better flexibility and processability compared with protective materials with a metal or ceramic plate, the various high performance fibers such as aromatic polyamide, ultra high molecular weight polyethylene, polybenzoxazole etc. are utilized to block the penetration or cut by sharp impactors. These stab resistant materials can be additionally enhanced when the movement of the individual

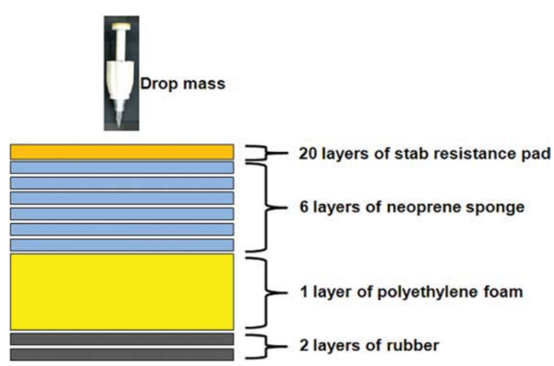



**Figure 3** Schematic diagram of the testing and backing material setup for drop tower testing. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

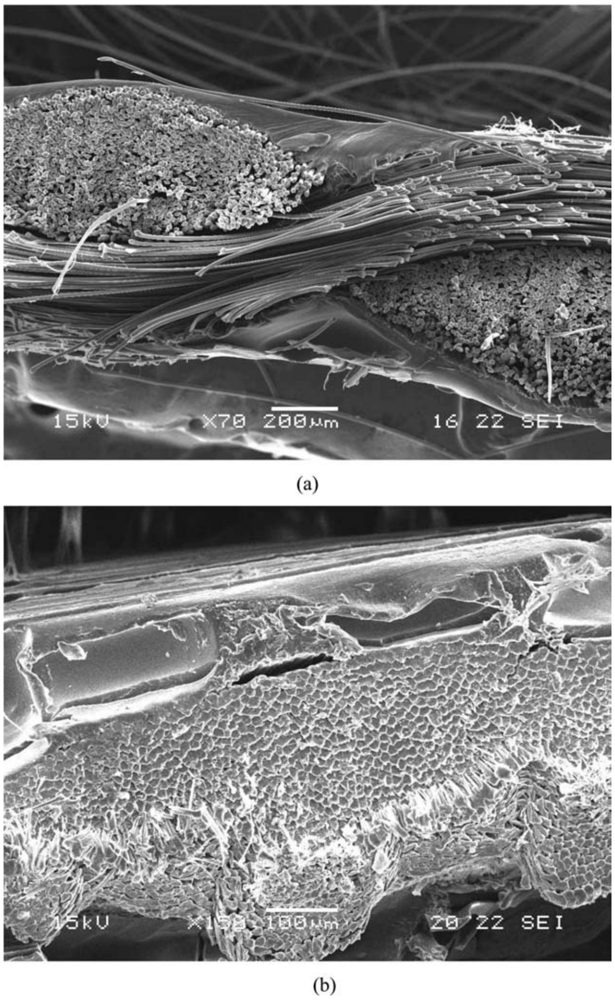



**Figure 4** Cross-sectional SEM images of the resin treated *p*-aramid fabrics. (a) PEB2 and (b) Ep6.

fiber bundle in the textile structure is elaborately controlled or reinforced with the polymeric resins. Various types of polymeric resins can be utilized for this purpose. Some thermoplastic resins with a low melting point have the advantage of flexibility and processability as well as a good adhesion to the fibers. Thermoset resins can also be used to further immobilize the fibers in textile structure because these resins provide additional reinforcement using their intrinsic physical strength.

In this study, commercial grade LDPE film, which has low melting point and good flexibility, was selected as a thermoplastic reinforcement. Since the physical strength of LDPE film is relatively weak compared with the strength of *p*-aramid fabric, it is expected that the effect of resin reinforcement on the stab resistance would not be sufficient. Also, as a thermoset reinforcement resin, BA-F based epoxy resin cured with PEA D230 was chosen because of the low viscosity and cure temperature of the resin.

Figure 4 shows the scanning micrographs of the cross-sectional view for the LDPE reinforced *p*-aramid fabric (PEB2) and epoxy reinforced *p*-aramid fabric (Ep6). Since the melt viscosity of LDPE is high and the compatibility between LDPE and *p*-aramid fiber is poor, LDPE resin does not penetrate inside the fabric structure but apparently coats on the fabric surface [Fig. 4(a)]. Most of the resin is concentrated in the intertwine points between warp and weft fiber bundles. However, since these resin lumps can act as reinforcing spots which prevent the movement of warp and weft fiber bundles, it seems that the resistance against sharp impactors might be improved.

On the other hand, the epoxy resin in Ep6 *p*-aramid fabric is completely impregnated and has penetrated into the gap between filament fibers of the fabric structure [Fig. 4(b)]. Therefore, it is expected that the epoxy resin reinforced *p*-aramid fabrics would show the higher stab resisting performance than the LDPE reinforced *p*-aramid fabric because the movement of fibers will be effectively restricted not only by the reinforcing effect of the cured epoxy resin but also by the uniform distribution of the resin.

### Stab resisting behaviors analyzed by quasi-static stab testing

Dynamic drop tower stab testing based on the NIJ Standard 0115.00 for stab resistance of body armor is designed to evaluate the actual performance of stab resistance assembly, and the overall stab resistance

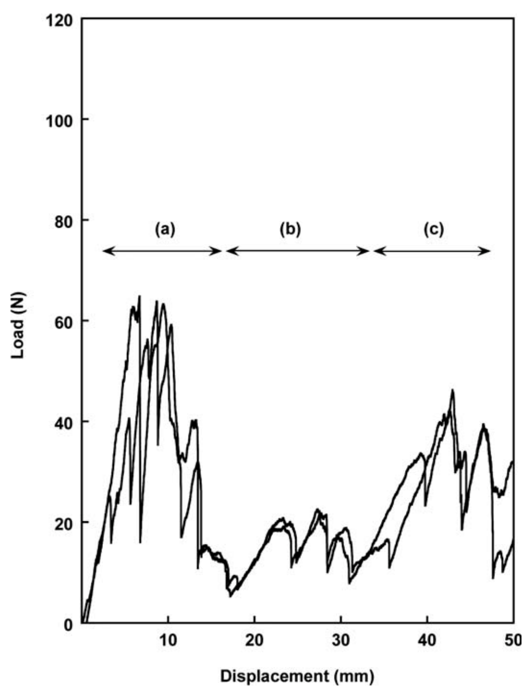
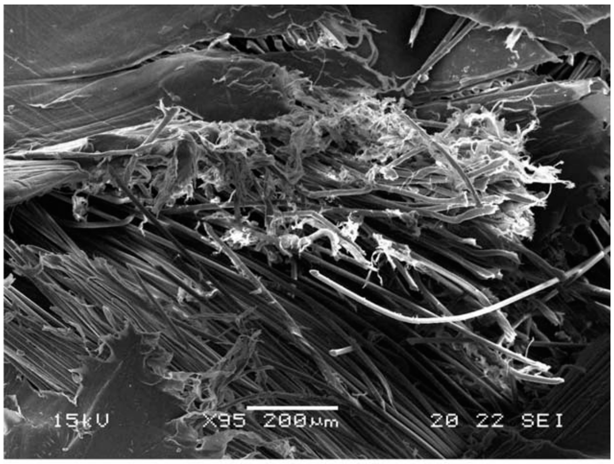
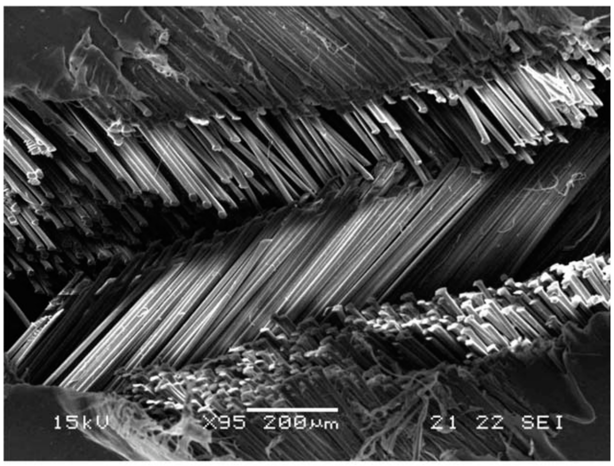



**Figure 5** Typical load-displacement curves of PES1 fabric against P1 impactor. (a) Initial puncture, (b) cutting, and (c) tear down of accumulated fiber bundles.




(a)




(b)

**Figure 6** Damaged PES1 fabric by P1 impactor. (a) Initial puncture and (b) cutting.

performance is represented in the penetration depth of the impactor. However, it is difficult to observe how each individual layer in body armor behaves to block the stab penetration. The quasi-static stab resistance test was widely used to evaluate the characteristics of the component materials composing stab protective gear.[11–14] This quasi-static testing is useful because it allows us to explore cut/puncture mechanisms for a particular impactor depending on the various penetrating rates. Also, the results of quasi-static testing are more reproducible than the results of dynamic drop tower stab testing.

### Differences of stab-resisting behaviors against different impactors

Figure 5 shows the typical stab resisting behavior of LDPE reinforced *p*-aramid fabric (PES1) against a knife (P1) impactor. It is obvious that the destruction by a P1 impactor which has the blade with a sharp edge can be observed in three distinctive steps. The initial puncture [Fig. 5(a)] by the point of the impactor gives the highest stab resistant strength throughout the stab resist process. It is well shown in the corresponding image of Figure 6(a) for the initial puncture step that the destruction in this step is due to the tearing of *p*-aramid fibers rather than the cutting of the fibers. The stress on the tip of the impactor is concentrated on a very small area of the fabric, and the *p*-aramid fibers are resisting to the tear destruction until the limit of its tensile strength.

The second is the cutting step [Fig. 5(b)] which shows the lowest stab resistance. Once the impactor has penetrated into the fabric structure after the initial puncture, the *p*-aramid fibers are easily cut by the sharp blade of the impactor. Furthermore, since *p*-aramid fiber has relatively poor shear strength and the movement of the fibers is limited by the fabric structure fixed with LDPE resin, the cutting destruction of the fibers is facilitated as shown in Figure 6(b).

Then, the accumulated fiber bundles which lie in the path of the impactor resist to the procession of the knife edge, leading to an increase of stab resistant strength. Although this step [Fig. 5(c)] is more easily observed from the nontreated *p*-aramid fabric, all samples in our experiment start to show similar behavior around a 35-mm penetration depth of the impactor. It is believed that the penetration depth of the fiber accumulation is closely related to the angle and shape of the blade as well as the fabric density.

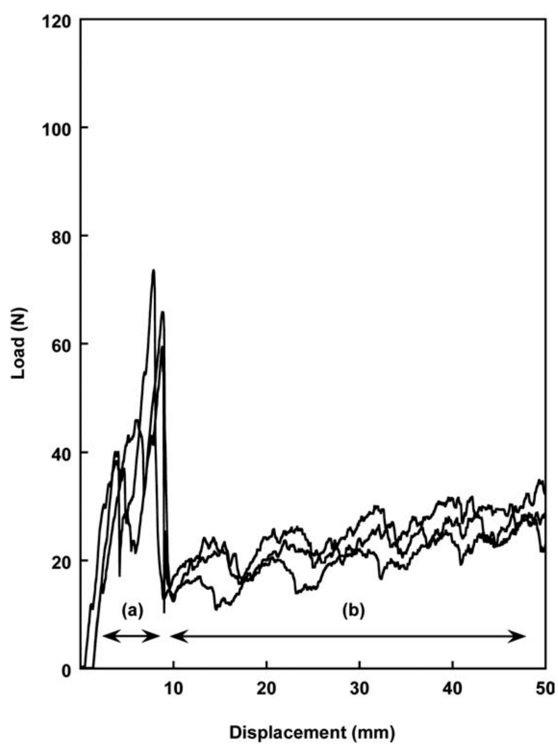



**Figure 7** Typical load-displacement curves of Ep4 fabric against P1 impactor. (a) Initial puncture and (b) cutting.

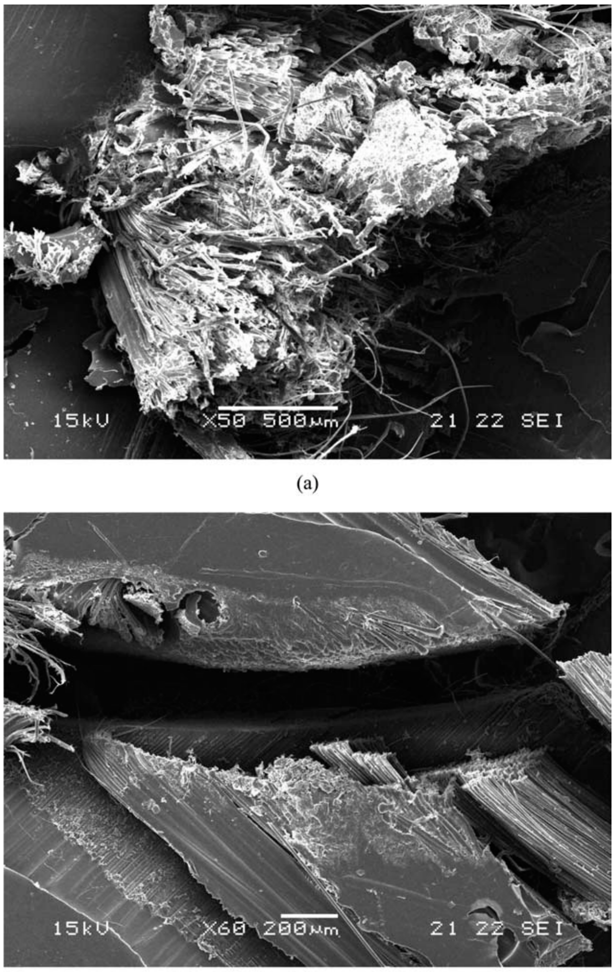



**Figure 8** Damaged Ep4 fabric by P1 impactor. (a) Initial puncture and (b) cutting.

On the other hand, the typical stab resisting behavior of epoxy resin reinforced *p*-aramid fabric (PES1) against a knife (P1) impactor is different from the behavior observed from LDPE reinforced fabrics. As shown in Figure 7, the destruction of the fabric is divided into only two steps of puncture and cutting. Since good adhesion between the fiber and epoxy resin holds the fibers effectively without any movement, the initial puncture is observed in a short displacement and the cutting of the fibers is facilitated without the fiber accumulation step. The enlarged image in Figure 8(a) gives a better explanation of the acute stab resistant behavior in the initial puncture step. It is well shown that the complete fibrillization of the *p*-aramid fibers is preceded during the initial puncture step because the epoxy resin holds the fibers tightly. Furthermore, with similar reason, well distributed epoxy resin inside the fabric structure as shown in Figure 8(b) as well as the strong adhesion between epoxy and fiber results in the clear cutting of the fiber bundles without fiber accumulation.

The typical stab resisting behaviors against a spike impactor is shown in Figure 9. Since a spike impactor has only a sharp tip along with long rod, the stab resisting behavior by a spike impactor is dominated by the initial puncture step. Once the sharp tip has penetrated into the fabric, the stab resistant strength is drastically decreased regardless of the resin reinforcements. In the case of LDPE reinforced *p*-aramid fabric, the tip of the spike impactor is penetrating into the fabric without tearing or cutting of the fibers as shown in Figure 10(a). On the other hand, as shown in Figure 10(b), the *p*-aramid fibers near the destruction area are severely fibrillized by the tear deformation due to the penetration of the spike impactor. This is very similar behavior to the behavior observed in the epoxy resin reinforced *p*-aramid fabric against a knife impactor.

### Evaluation of stab resistant strength

The stab resistant strengths of the LDPE reinforced *p*-aramid fabrics against a knife impactor are shown in Figure 11. The maximum stab resistant strength of the fabric is representing the maximum load by initial puncture which is corresponding to the value in Figure 5(a). The stab resistant strengths for the cutting step and fiber accumulating step are calculated by the average load values for the corresponding steps in Figure 5(b,c), respectively. It is

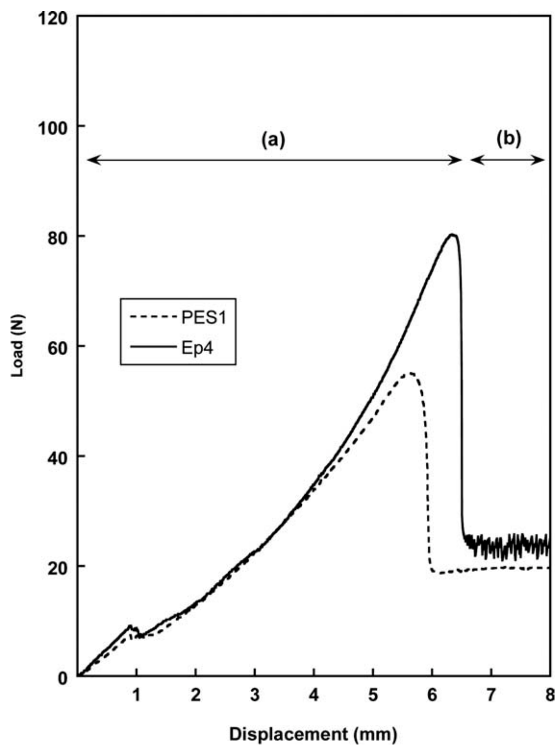



**Figure 9** Typical load-displacement curves of PES1 and Ep4 fabric against spike impactor. (a) Initial puncture and (b) penetration.

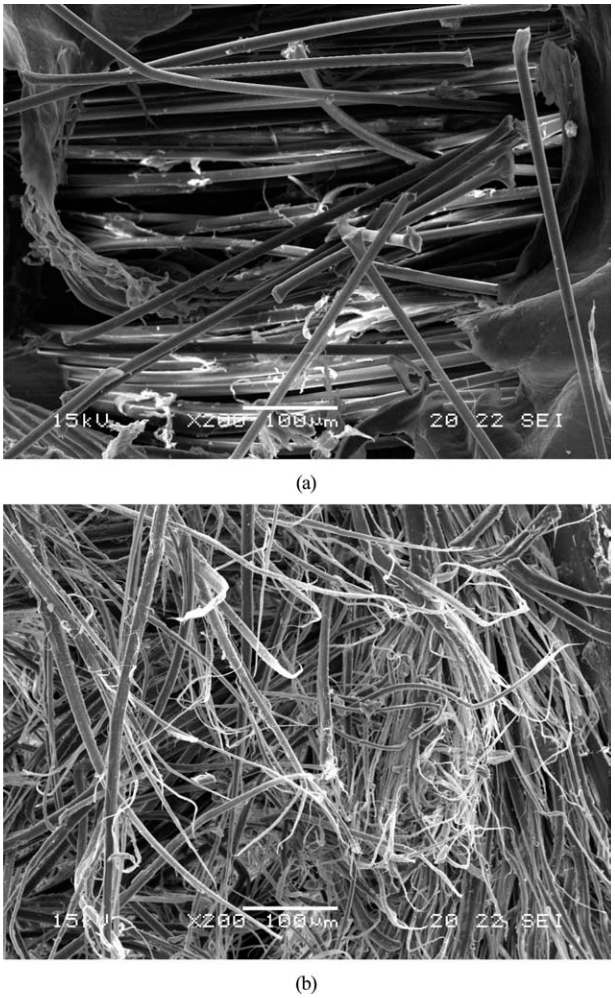



**Figure 10** Damaged fabrics by spike impactor. (a) PES1 and (b) Ep4.

obvious that the maximum stab resistant strength is increased by the LDPE reinforcement. The *p*-aramid fabric reinforced with LDPE on both sides (PEB2) shows the highest increment of the strength from 55 N to 77 N.

However, even though the *p*-aramid fabric reinforced with LDPE on a single side (PES2) has the same resin add-on as PEB2, the maximum stab resistant strength of PES2 is almost identical to the value of PES1 which has relatively low resin add-on. This means that the applying mode of reinforcing resin as well as the amount of applied resin is also affecting the strength of the initial puncture step. The fact that PES2 does not have the benefit of more resin reinforcement than PES1 implies that the additional LDPE resin cannot effectively fix the movement of the fibers. Hence, since the stab resistant strength of the initial puncture step is closely related to the movement of the fibers, PES2 shows much lower stab resistant strength than PEB2 which has the same resin add-on but on both sides. Additionally, it is interesting that the stab resistant strengths for the cutting step and fiber accumulating step are decreased with the increase of the resin add-on. Although the better immobilization of the fibers, which results in a higher maximum stab resistant strength for the initial puncture step, can be obtained by the increase of the resin amount, this immobilization of the fibers acts as an unfavorable factor for the cutting step rather than a constructive factor.

With similar reason, as shown in Figure 12, the stab resistance for the cutting step of epoxy reinforced *p*-aramid fabrics shows comparatively lower values than the stab resistance for the initial puncture step. The maximum stab resistant strength by initial puncture is steadily increased with the increase of epoxy resin add-on up to 42.7% (EP6 sample). Also, unlike the LDPE reinforced samples, the stab resistant strength for the cutting step is not decreased with the increase of epoxy resin add-on. This is closely related to the characteristics of bulk epoxy resin which has higher strength than soft LDPE resin. Furthermore, it is believed that the good adhesion and distribution of epoxy resin with the fibers form an ideal composite structure which can efficiently resist to knife movement.

On the other hand, as shown in Figures 13 and 14, the stab resistance against a spike impactor shows a different behavior compared with the behavior against a knife impactor. While the increment of stab resistance

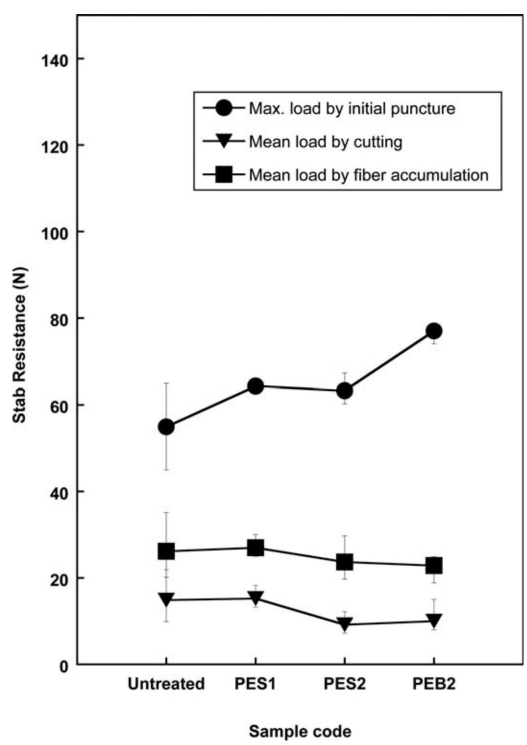



**Figure 11** Stab resistance of LDPE reinforced *p*-aramid fabrics against P1 impactor.

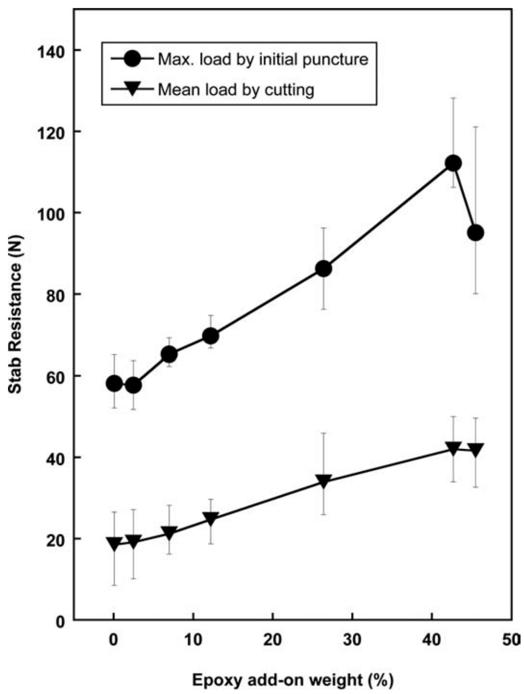



**Figure 12** Stab resistance of epoxy reinforced *p*-aramid fabrics against P1 impactor.

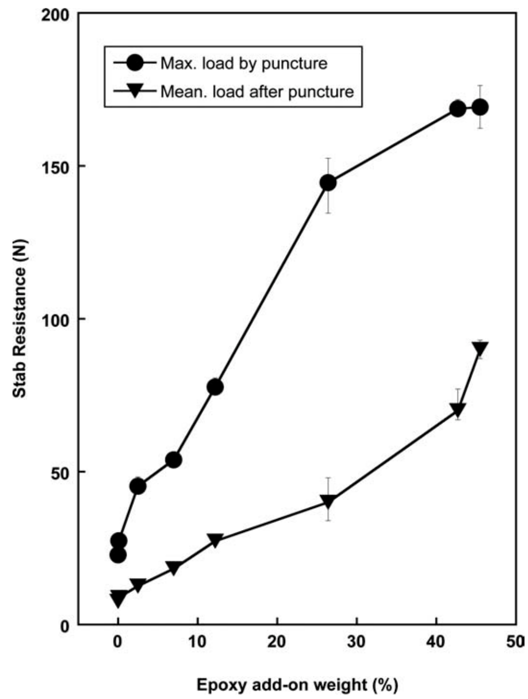



**Figure 14** Stab resistance of epoxy reinforced *p*-aramid fabrics against spike impactor.

of LDPE reinforced fabrics is not significantly changed, the stab resistances of epoxy reinforced fabrics are greatly increased to more than 600% in maximum load. It is also shown that the noticeable improvement of the strength after penetration, which is very low as shown in Figure 9(b) due to the poor integrity of fabric structure, is obtained. This means that the tighter the fabric structure is confined by the reinforcing resin, the higher the stab resistance is increased. Therefore, when high stab resistance strength against a spike impactor is required, an immobilization of the fabric structure becomes important.

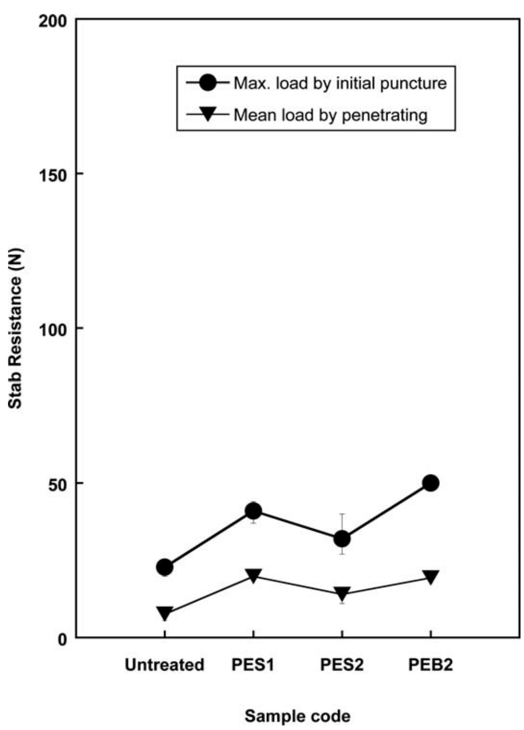



**Figure 13** Stab resistance of LDPE reinforced *p*-aramid fabrics against spike impactor.

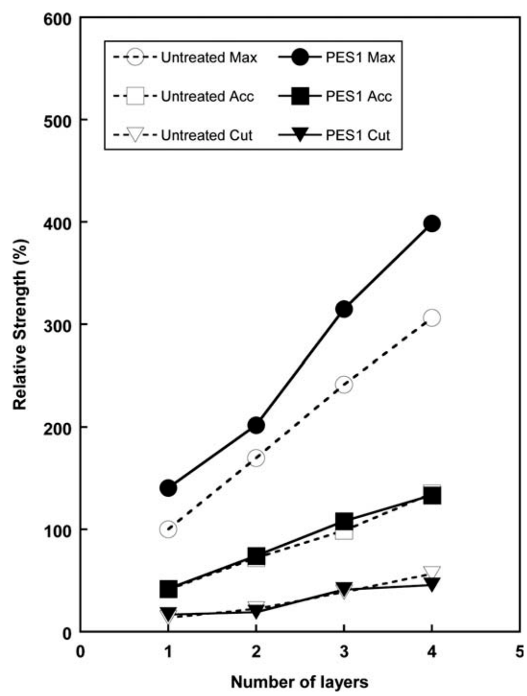



**Figure 15** Comparison of stab resistance for layered *p*-aramid fabrics and PES1 against P1 impactor.

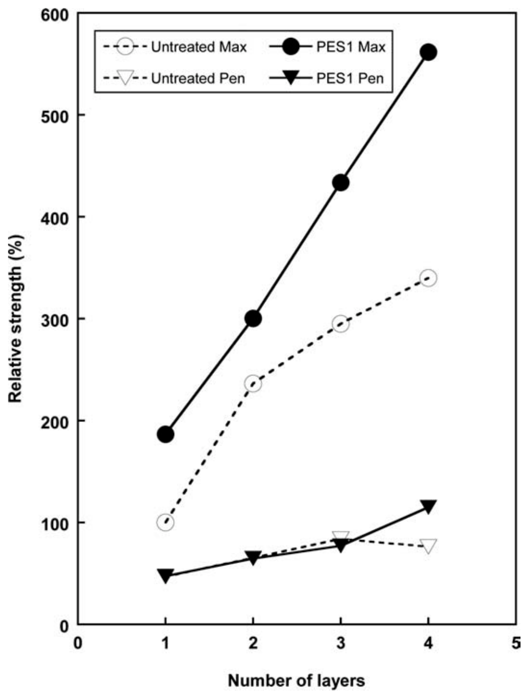



**Figure 16** Comparison of stab resistance for layered *p*-aramid fabrics and PES1 against spike impactor.

## Effect of multilayer on the stab resistance

The satisfactory level of body protection against stab threats is generally achieved by utilizing many layers of stab resistant materials to increase the stab resistant strength as well as to give the appropriate dexterity to wearers. Therefore it is important to compare the stab resistant strength of materials when they are layered. Figure 15 represents the relative strength of the layered PES1 fabrics to the maximum stab resistant strength of untreated single *p*-aramid fabric against a knife impactor. As expected, the more fabrics are layered, the higher the stab resistant strength is obtained. Also, the improvement of stab resistant strength by LDPE reinforcement over untreated fabrics is clearly shown especially in the case of maximum stab resistant strength. However, it is interesting that the LDPE reinforcement does not assist at all to increase the stab resistant strengths in both the cutting step

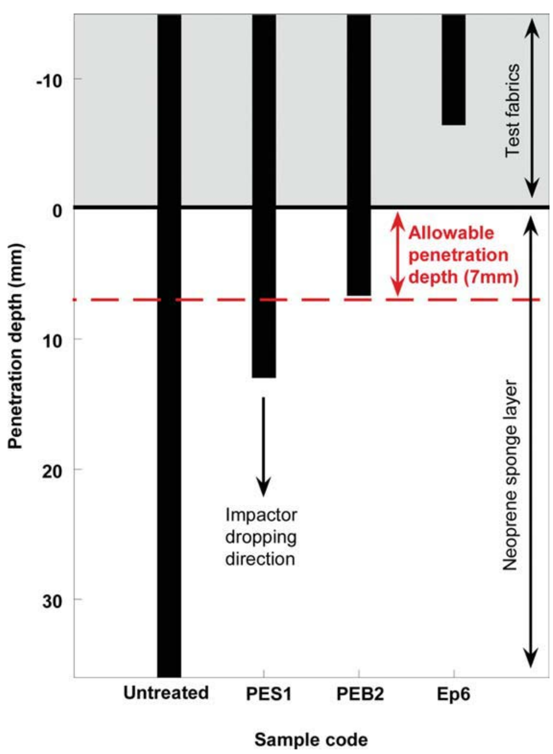



**Figure 17** Drop tower stab testing results for resin reinforced *p*-aramid fabrics against S1 impactor. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

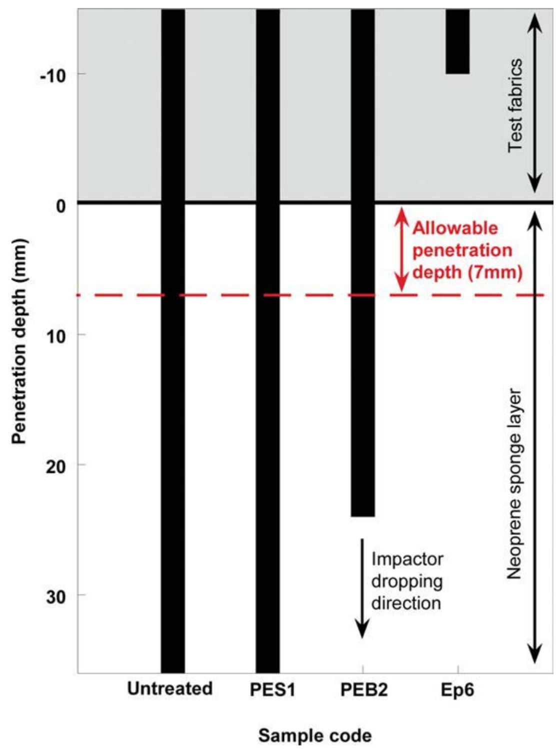



**Figure 18** Drop tower stab testing result for resin reinforced *p*-aramid fabrics against spike impactor. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

**TABLE III**
**Drop Tower Stab Testing Results for the Resin Reinforced *p*-Aramid Fabrics**

| Sample code | No. layers | Total thickness (mm) | Penetration depth (mm) | |
|---|---|---|---|---|
| | | | Knife impactor | Spike impactor |
| Untreated | 20 | 11.4 | Over 36.0 | Over 36.0 |
| PES1 | 20 | 12.6 | 13.0 | Over 36.0 |
| PEB2 | 20 | 15.7 | 6.7 | 24.0 |
| Ep6 | 20 | 14.3 | −6.4 | −10.0 |

and accumulation step. Figure 16 for the spike impactor shows a much clearer difference in the maximum strengths between untreated and LDPE reinforced fabrics. This means that LDPE reinforcement can provide a better protection against an initial penetration for both impactors, however, the stab resistant strength after the penetration cannot be improved by the soft LDPE reinforcement.

### Dynamic stab testing result using drop tower apparatus

The 20 layers of *p*-aramid fabrics reinforced with the different polymeric resins are examined by the NIJ Standard 0115.00 to compare the practical stab resistant strength of body armor materials. The penetration depth of a certain impactor through the stab resistant materials is defined as a stab resistant performance. The results are shown in Figures 17 and 18 for the knife impactor and spike impactor, and summarized in Table III. It is obvious that, from the fact that the impactors are completely penetrated into the bottom of the testing apparatus, the untreated *p*-aramid fabrics are not able to resist the threats. On the other hand, the 20 layers of PEB2 fabric effectively block penetration of the knife impactor less than 7 mm which is the allowable penetration depth for the "E1" energy level 1 defined in NIJ standard 0115.00. This means that the LDPE reinforcement can drastically decrease the numbers of *p*-aramid fabric layers, leading to the possible construction of a more light weight and flexible body armor materials. However, the stab resistant performance of PEB2 fabrics against a spike impactor is not sufficient due to the poor stab resistance of each single layer. Although the epoxy treatment makes *p*-aramid fabric stiffer than an untreated one, EP6 fabric efficiently blocks the penetration against both impactors. Therefore, it is expected that higher stab resistant materials with more flexibility can be obtained by the optimization of a number of layers and components design using two different fabrics. This optimization of material design will be further reported in the study.

## CONCLUSIONS

The flexibility and toughness of polymeric resin which are used for reinforcing *p*-aramid fabric are closely related to the stab resistant performance, and the stab resistant behavior is closely related to the shape of the impactors whether it is a knife or a spike. The destruction behavior of the LDPE reinforced *p*-aramid fabrics against a knife impactor shows three distinctive steps; the initial penetration step with maximum strength, the cutting step by knife edge, and the destruction step of accumulated fiber bundles. On the other hand, the epoxy resin reinforced *p*-aramid fabrics against a knife impactor exhibit just two steps without the accumulation of fiber bundles. In the case of a spike impactor, the maximum stab resistant strength is observed from the initial penetration step for both polymeric resins, however, the stab resistant strength after initial penetration drastically decreased regardless of the reinforcing resins.

Also, it is clearly shown that the improvement of stab resistant strength by LDPE reinforcement is linearly proportional to the number of layers especially in the case of maximum stab resistant strength obtained from the initial penetration step. However, the stab resistant strengths obtained from the cutting step or the accumulation step do not acquire a benefit from the LDPE reinforcement.

From the dynamic drop tower testing results for 20 layers of *p*-aramid fabrics reinforced with the different polymeric resins, it is found that PEB2 and Ep6 fabrics effectively block the penetration of knife impactor less than the allowable penetration depth for "E1" energy level 1 defined in NIJ standard 0115.00. PEB2 fabric does not give a sufficient protection against a spike impactor due to the poor stab resistance of each single layer. However, although the epoxy treatment makes *p*-aramid fabric stiffer than an untreated one, EP6 fabric shows excellent protective performance against both impactors.

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