Ramie, Cotton, and Rayon Double Ply Combination Composite for Bullet Proof Vests Body Armor

K Setyani and N Aryanti
Department of Chemical Engineering, Diponegoro University, Tembalang, Semarang

*Corresponding author: kanthi.setyani@gmail.com

Abstract. The bullet proof vest from composite fiber double ply from combination of ramie, cotton, and rayon, have been studied in order to improve the bullet proof vest in previous research using composite of pure ramie fiber. The mechanical bonding of the composite reinforced natural fiber can be increased by using chemical treatment of fiber or by using the addition of coupling agent. The chemical treatment, for example alkali treatment, is often used because it is more cost-effective. By increasing mechanical bonding also increasing the tensile strength of the composite so that this material could restrain the impact of the bullet. The result shows that the tensile strength of the composites have the optimum values for 30 minutes treated fiber in a 5% NaOH solution, i.e. 13.31 MPa, the tensile test specimens were produced according to ASTM D-638. This research is to investigate the ability of the double ply fabric itself from the bullet impact, the fiber composite and also the combination of fiber composite as a front layer (Panel A) and the double ply fiber as a second layer (Panel B) for a bullet proof vest. Optimal combination is obtained with 5 layers of panel A and 20 layers of panel B which is able to protect against cal. 7.65 mm x 17 mm (.32 ACP) bullet fired through .32 Pindad pistol from a distance of 10 meters. Panel with a size of 20 cm x 20 cm has a total thickness of 14.69 mm and a total weight of 454.73 gram. Scanning electron microscopy (SEM) observations indicated that the porosity and surface area of the fiber is smooth, fiber surfaces showed topography with microporous. SEM also showed well-arranged structure of fibers bonding. Energy Dispersive X-ray (EDX) analysis indicated 99.6% carbon contents in ramie-cotton-rayon fiber. Test result indicates that panel from composite ramie-cotton-rayon-epoxide can reach the level 1 of International Standard of NIJ-010104. Compared to panel from pure ramie fiber, the panel from this composite (0.454 kg) is lighter than previous research (0.52 kg). This combination can restrain the bullet from 10 meters distance, shorter than the previous research in 20 meters distance.

Keywords: bulletproof vest; epoxide; natural composite; alkali treatment

1. Introduction

Ballistic protection equipment, such as a bulletproof vest, is soldier’s most important means of preserving life and survivability in extreme combat conditions. The bulletproof vests are designed to protect the user’s chest from injury without disturbing the ability to perform his duties [1]. Aromatic polyamide or aramid fibers known under the trade name Kevlar, Trawon and so is synthetic fiber
materials commonly used in the manufacture of bulletproof vests. This synthetic fibers have high
tensile strength and ductility [1]. Kevlar is expensive and not available in Indonesia.

Earlier study in 2009, the Center for Textile conduct bulletproof vest research with raw
material of polyester fiber, the weight of the panel reached 1,642 kg. This panel was tested with a .38 Special bullet. The recent research of ramie single ply fiber-combined with epoxy resin bulletproof panel, that tested with .32 ACP (FMJ) bullet in 20 meters distance, with average speed \( V_{20} = 267 \text{ m/s} \), the weight of the panel is 0.52 kg, consisting of 48 layers of ramie, 16 layers panel A and 32 layers panel B. [3]. High tensile strength fabric may be fabricated by increasing thread density to increase the number of weave intersections per unit length, constructing the fabric from blended yarn with one or more strong fiber, and using strong type of yarn. [4]. Those are the reasons why ramie, cotton and rayon double ply combination is used in this research. Two or more threads woven together to get a strong type of yarn, with combined mechanical properties of each fiber in order to get a strong fabric construction.

2. Material and Method

Raw material used in this study was ramie combination cotton-rayon double ply fabric acquired from Denpasar, Bali and resin epoxy acquired from the market. Alkali Solution was made from making 5% NaOH solution by dissolving 50 grams of NaOH with 950 grams of water in a glass beaker, then by stirring until all solids dissolved completely. Epoxide made by mixing resin and hardener in appropriate specified ratio, then stirring gently until the solution became homogeneous (±2 minutes in 200 ml mixture) in the beaker glass, then left at room temperature until dry/solid hard.

Specimen ASTM D638 made from the ramie ply combined with rayon-cotton ply cloth. The cloth was cut in size of 20 cm x 20 cm and was soaked in alkali (NaOH) 5% for various minutes. While, the epoxide resin is prepared by mixing 1 part hardener with 5 parts of resin, then stirred gently until homogeneous. Epoxide resin was applied to the surface of the cloth until several layers. Epoxide resin functions also as adhesive between the cloths. Combination of cloth-epoxy is pressed manually. Then left at room temperature until dry/harden. The dried panel was cut according to ASTM D-638[6] standard, then the specimen was used for tensile strength test.

There are 3 types of panel to be test-fired. First is prepared from 10-50 layers of ramie-
cotton-rayon cloth with size 20 cm x 20 cm without resin epoxy (as panel B). Second, prepared from 5-18 layers ramie-cotton-rayon cloth size 20 cm x 20 cm which had been alkali treated then glued together with epoxy resin ratio 1 hardener : 5 resin and allowed to dry/harden for ±6 hours (as panel A). Third, 5 of ramie-cotton-rayon cloth size 20 cm x 20 cm which had been alkali treated glued together with epoxy resin ratio 1 hardener : 5 resin and allowed to dry/harden for ±6 hours (as panel A). 20 layers of ramie-cotton-rayon cloth size 20 cm x 20 cm without resin epoxy was prepared for panel B. Panel A is used as front surface of panel B.

Tensile strength analysis of epoxy ramie-cotton-rayon panels was carried out in the Laboratory of the Department of Mechanical Engineering of Politeknik Negeri Malang. The specimens and testing process were prepared using ASTM D-638 standard. Tensile strength is the maximum stress that a structure can hold under tensile conditions. The \( \sigma-\varepsilon \) curve shows that after the maximum stress point, the stress continues to rise with the continuation of plastic deformation to the maximum point and then decreases until it finally breaks. Tensile strength is the maximum load divided by the initial cross-sectional area of the test object. This strength is useful for the purposes of specification and quality control of materials. The tensile strength value was obtained from the Tarno Grocki test equipment.

Penetrating power analysis was done by shooting a ramie-cotton-rayon-epoxide panel with .32 ACP ammunition at a distance of 10 m. The distance was set at 10 m in order to get higher bullet speed and greater impact of the bullet than the last research. The bullet speed at 20 m, \( V_{20} = 267 \text{ m/s} \),
becomes $V_{10} = 290 \text{ m/s}$ at 10 m distance from the gun. Weight analysis is done by weighing bulletproof panel with digital analytic balance. The lightest panel weight that is able to withstand the bullet impact will be selected in order to provide protection, while maintaining comfort, keeping optimum mobility and speed [7]. Thickness analysis was done by measuring the thickness of bulletproof panel with digital vernier calipers. This analysis will not determine the thinnest panel, but only determine the thickness of the optimal bulletproof panel (the lightest bulletproof panel that can withstand bullet impact). SEM (Scanning Electron Microscopy)-EDX (Energy Dispersive X-ray) analysis is performed with 1000x, 1500x, and 2000x magnification. Scanning Electron Microscopy (SEM) is a tool used to observe small specimens. The process of checking with SEM is as following. The microstructure is observed repeatedly using electron beam, generally 1 μm length. The surface of the specimen was photographed using SEM and analyzed in order to obtain condition of the specimen, whether it was damaged or not [8]. SEM is the importance of giving a real picture of a small section of the specimen, which means we can analyze fiber size, bonding and roughness.

3. Result and Discussion

The effect of alkali treatment on the tensile strength of the composite, soaking the ramie-rayon-cotton combination fabric in 5% NaOH solution with immersion time variables can be seen in table 1. The tensile strength test was carried out according to ASTM D-638 standard.

| Immersion time (minute) | Tensile strength (MPa) | Elongation | Young’s Modulus (MPa) |
|------------------------|------------------------|------------|----------------------|
| 0                      | 11.96                  | 0.80       | 14.95                |
| 30                     | 12.25                  | 0.90       | 13.61                |
|                        | 12.08                  | 0.80       | 15.10                |
|                        | 13.31                  | 0.80       | 16.84                |
| 60                     | 12.48                  | 0.70       | 17.83                |
|                        | 12.99                  | 0.80       | 16.23                |
|                        | 10.38                  | 0.70       | 14.83                |
| 90                     | 11.18                  | 0.80       | 13.97                |
|                        | 10.40                  | 0.70       | 14.86                |
|                        | 9.79                   | 1.50       | 6.52                 |
| 120                    | 10.14                  | 1.20       | 8.45                 |
|                        | 8.49                   | 1.10       | 7.72                 |
|                        | 5.72                   | 0.80       | 7.15                 |
|                        | 4.83                   | 0.70       | 6.90                 |
|                        | 4.81                   | 0.60       | 8.02                 |

Table 1 shows that the alkali treatment affects the increase of tensile strength the most, at the soaking time of 30 minutes in a 5% NaOH solution. While the longer soaking time reduce the tensile strength further. This NaOH treatment aims to dissolve wax-like layers on the surface of the fiber, such as lignin, hemicellulose, and other impurities. With the loss of this lignin, the bond between fiber
and matrix becomes stronger, so the tensile strength of the composite increases. However, longer NaOH treatment can cause damage to cellulose. In fact, cellulose is the main substance that provides fiber strength. As a result, the fibers subjected to the alkali treatment too much will suffer significant degradation. As a result, ramie fiber-reinforced composites with longer alkali treatments have lower strength [9].

**Table 2. The Ballistic Test Resistance of Panel B**

| No | Number of layers | Thickness (mm) | Weight (gr) | Penetration |
|----|------------------|----------------|-------------|-------------|
| 1  | 10               | 6.18           | 118.40      | Perforated  |
| 2  | 15               | 9.55           | 177.60      | Perforated  |
| 3  | 20               | 11.55          | 236.80      | Perforated  |
| 4  | 25               | 12.87          | 296.00      | Perforated  |
| 5  | 30               | 14.99          | 355.20      | Perforated  |
| 6  | 35               | 16.16          | 414.40      | Perforated  |
| 7  | 40               | 18.84          | 473.60      | Perforated  |
| 8  | 42               | 19.45          | 497.28      | Perforated  |
| 9  | 45               | 21.08          | 532.80      | Withstand   |
| 10 | 48               | 21.94          | 568.32      | Withstand   |
| 11 | 50               | 22.76          | 592.00      | Withstand   |

Table 2 shows that the cloth without epoxy-resin is able to withstand a bullet on the 45th layer with a weight of 532.80 grams and thickness of 21.08 mm. In the previous study, it was discovered that a bullet could still penetrate 50 layers of ramie from 20 meters distance. This shows that the type of thread spinning affects the tensile strength of fabric. [7]

**Figure 1.** Panel B restrained the bullets in 45 layers (left – front side; right – back side)
Table 3. The Ballistic Test Resistance of Panel B

| No | Ratio Hardener : Resin | Number of layers | Thickness (mm) | Weight (gr) | Penetration           |
|----|-----------------------|------------------|----------------|-------------|----------------------|
| 1  | 1 : 5                 | 5                | 3.14           | 217.93      | Perforated           |
| 2  | 1 : 5                 | 8                | 5.10           | 348.68      | Perforated           |
| 3  | 1 : 5                 | 10               | 7.66           | 435.86      | Perforated           |
| 4  | 1 : 5                 | 13               | 10.55          | 566.22      | Pierced, stuck       |
| 5  | 1 : 5                 | 16               | 11.68          | 697.38      | Ricochet             |
| 6  | 1 : 5                 | 18               | 13.85          | 784.55      | Ricochet             |

Table 3. shows that panels with 13-layer cloth is pierced by the bullet, but the bullet is still intact in the panel. This is because the combination of ramie fabric with epoxy resin is so hard and strong, but provides a large impact on the back of the panel. In addition, this is not compatible with the requirements of a bulletproof vest that the vest must be able to keep the bullet lodged in the panel while remaining un-pierced. In the event that a bullet ricocheted from the panel, it can potentially harm any bystander. Naturally, epoxy resins are hard materials and modifications are needed to be able to withstand large impacts with softer but tough materials. For example, soft on the front, but hard on the inside so that the bullet can lodged in a way that doesn't bounce. An effective method for this purpose is to modify epoxy resin with liquid rubber [10]. Examples of the shape of the ramie-epoxy panel after shooting can be seen in Figure 2.

![Figure 2. Panel A - Ricochet bullets in 16 layers (left – back side of panel; right – front side of panel)](image-url)
Table 4. The Ballistic Test Resistance of Panel A combined with Panel B

| Number of layers | Weight (gr) | Thickness (mm) |
|------------------|-------------|----------------|
| Panel A | Panel B | Panel A + B | Panel A | Panel B | Panel A + B | Panel A | Panel B | Panel A + B |
| 5     | 20 | 25 | 217.93 | 236.80 | 454.73 | 3.14 | 11.55 | 14.69 |
| 8     | 15 | 23 | 348.68 | 177.60 | 526.28 | 5.10 | 9.55 | 14.65 |
| 10    | 10 | 20 | 435.86 | 118.40 | 554.26 | 7.66 | 6.18 | 13.84 |

Table 4 shows that the bullet were lodged in the panel B as shown in figure 3. When the panel retains the penetration of the bullet, the impulse of the bullet is reduced by spreading its momentum throughout the body [1]. Users will still feel the kinetic energy of the bullet, this can cause bruising, swelling or serious internal injuries. The combination of panel A and panel B manages to make bullet lodged because the energy and speed of the bullets have decreased a lot when pounding the very hard panel A, then the remaining energy and the speed of the bullets are inhibited by panel B which consists of ramicotton-rayon fabric layer, which has high tensile strength. The fabric that has a high tensile strength is able to withstand the residual pressure of bullet kinetic energy. When exposed to pressure from a bullet, fabric fiber layers stretch and absorb the kinetic energy and disperse it through the vest, so the energy is not enough to make the bullet penetrate the vest. Based on calculations, the panel in this experiment was able to withstand a .32 ACP bullet speed of 290 m/s at a distance of 10 meters. The .32 ACP bullet at 290 m/s has an energy penetration of 198.896 Joules and a momentum of 1.372 kg.m/s.

Figure 3. Pierced through panel A and restrained in panel B

The strength of ramie, rayon and cotton fiber combination is originated from cellulose as the major constituent of ramie fiber. Cellulose has the formula (C₆H₁₀O₅)ₙ, where "n" is the degree of polymerization and most of the ramie fiber consists of ± 75% cellulose. Analysis of Frenderberg, Haworth and Braun in the book Textile Fiber indicating that cellulose is formed by a ring of glucose, so it can be mentioned that the structure of cellulose fibers is the unity of anhydrous glucose connected to one another by oxygen bounds in position 1-4 [12]. In plant, cellulose molecules are arranged in the form of fibrils composed of several parallel molecules linked by glycosidic bonds so it is difficult to
be outlined. The chemical composition and structure thus makes most materials containing cellulose is strong and hard [13].

EDX analysis of ramie combination fiber shows that it contains 99.6% carbon that came from carbon chains to form cellulose. Cellulose is never found in nature in a pure state, but always associated with other polysaccharides such as lignin, pectin, hemicellulose, and xylan [13]. Most composition of ramie consists of cellulose that is an organic material which has a chemical structure consisting of carbon [4][16][17]. Cellulose is one of the criteria that indicate the strength of the fiber [12]. Most cellulose associated with lignin so often referred to as lignocellulose. Cellulose, hemicellulose and lignin produced from photosynthesis. Cellulose is a structural polysaccharide that serves to provide protection, shape, and a buffer to the cells and tissues [12]. Naturally molecules are arranged in the form of cellulose fibrils which consist of several cellulose molecules connected by glycosidic bonds. These fibrils form a crystalline structure which is covered by lignin. The chemical composition and structure thus makes most materials containing cellulose is strong and hard. Strong and hard nature possessed by most of the cellulose material that makes the material resistant to enzymatic decomposition. Naturally cellulose decomposition takes place very slowly [12]. The content of cellulose and lignin is one of the criteria that indicate the strength of the fiber. Excellent mechanical properties of the cellulose are strain, strength, resistance to pressure, it expands and increases permeability properties continue during the process of forming the wall [12].

In addition, SEM analysis (Fig. 4) shows that the image of ramie combination fiber that woven by machine are more regularly structured, tightly bounded fibers and the fiber’s surface looks smoother (microporous), so it is not easily broken when hit by pressure. So it gives good performance of ramie combination cloth that is able to withstand the pressure of the bullet on the Table 3.

Figure 4. SEM (Scanning Electron Microscopy) Analysis of ramie-rayon-cotton cloth
In Table 3, the lighter weight panel pierced by bullet is 454.73 gram. Compared to panel A and B which is heavier and thicker (Table 5), it can withstand the bullet. This proves that the existence of panel B that consist of a pure ramie cloth that has a high tensile strength give significant effect.

**Table 5. Comparison of Ballistic Test Results of 3 Panels**

| Experiment | Panel | Number of layers | Thick (mm) | Weight (gr) | Penetration |
|------------|-------|------------------|------------|-------------|-------------|
| 1          | Rami, rayon, cotton cloth (B) | 45 | 21.08 | 532.80 | Withstand |
| 2          | Rami, rayon, cotton cloth+epoxy resin (A) | 16 | 11.68 | 697.38 | Withstand |
| 3          | A + B | 25 | 14.69 | 454.73 | Withstand |

**Figure 5. Graph Total Weight vs Total Number of Panel**

The graph (Fig. 4) shows that the combination of panel A 5 layers and panel B 20 layers have lighter weight than another panel combinations. Which total weigh is 454.73 grams and thickness between 14.69 mm. Data weight and thickness is per 20 cm x 20 cm = 400 cm².

The panel can withstand .32 ACP bullet that according to International standard NIJ 101004 (Table 6). This panel include the level I [15]. Kevlar fabric need 9-10 layers to restrain bullet for NIJ level I. (http://pinnaclearmor.com)
Table 6. Standard International NIJ 101004

| Level | Type of Bullet       | Weight of Bullet (gr) | Impact of Velocity (m/s) |
|-------|----------------------|-----------------------|--------------------------|
| I     | .22 cal LR, LRN      | 2.6                   | 329                      |
|       | .380 ACP, FMJ RN     | 6.2                   | 322                      |
| IIA   | 9 mm, FMJ RN         | 8                     | 341                      |
|       | .40 S&W FMJ          | 11.7                  | 322                      |
| II    | 9 mm, FMJ RN         | 8                     | 367                      |
|       | 0.357 Mag JSP        | 10.2                  | 436                      |
| IIIA  | 9 mm, FMJ RN         | 8.2                   | 436                      |
|       | .44 Mag SJHP         | 15.6                  | 436                      |
| III   | 7.62 mm NATO FMJ     | 9.6                   | 847                      |
| IV    | .30 cal M2AP         | 10.8                  | 878                      |

Note:
- AP = Armor Piercing
- FMJ = Full Metal Jacked
- JSP = Jacked Soft Point
- LRHV = Long Rifle High Velocity
- RN = Round Nose
- SJHP = Semi-Jacketed Hollow Point
- SWC = Semi-wadcutter

4. Conclusion

Test result indicates that panel from composite ramie-cotton-rayon-epoxide can reach the level 1 of International Standard of NIJ-010104. This combination can restrain the bullet from 10 meters distance. The number of layers of panel A is 5 layers and panel B is 20 layers which produce vest weight according to standards is 454.73 grams per 400 cm².

Acknowledgement

The authors acknowledge PT PINDAD for providing their facilities for Ballistic Test.

References

[1] Carr, D. dan Lewis, E. A. (2014). Ballistic-protective clothing and body armour.
[2] Agus Surya, M, Arif Wibisana, Zubaidi, K., (2015). Identifikasi Sifat Fisik dan Sifat Termal Serat-Serat Selulosa untuk Pembuatan Komposit.
[3] Nunung Kristiana. (2015). Kombinasi Serat Rami dan Matrik Epoksi Sebagai Rompi Anti Peluru. Teknik Kimia, Universitas Diponegoro.
[4] Angelini, L.G., Lazzeri, A., Levita, G., Fontanelli, D., Bozzi, C.. (2000). Ramie (Boehmeria nivea (L.) Gaud.) and Spanish Broom (Spartium junceum L.) fibres for composite materials: agronomical aspects, morphology and mechanical properties. Italy: University of Pisa.
[5] Gong, R.H., _Specialist Yarn and Fabric Structures: Developments and Applications_, Oxford Cambridge Philadelphia New Delhi, Woodhead Publishing Limited, 2001.

[6] ASTM, _Annual Book of ASTM Standard_, West Conshohocken, 2003.

[7] Zubaidi, Moekarto, M., Santoso, S. (2009). _Pembuatan Rompi Anti Peluru Menggunakan Bahan Dasar Serat Poliester_. Bandung: Balai Besar Tekstil: Arena Tekstil Vol 24 No. 2.

[8] Parilaraya, Nandaza. (2015). _Pengaruh variasi panjang serat terhadap kekuatan impact komposit berpengaruh serat rami dengan matriks polyester_. Teknik Mesin, Universitas Lampung.

[9] Kuncoro Diharjo. (2006). _Pengaruh Perlakuan Alkali Terhadap Sifat Tarik Bahan Komposit_. Jurnal Teknik Mesin Universitas Petra ISSN: 1410-9867 Vol. 8 No.1: 8-13.

[10] Takeichi, T. dan Furukawa, N. (2012). _Chemistry and Technology of Polycondensates | Epoxy Resins and Phenol-Formaldehyde Resins_. Toyohashi, Japan, Sasebo National College of Technology, Nagasaki.

[11] Moeliono, M. dan Siregar, Y. (2012). _Rekayasa Bahan Baku Sutra dan Limbah Kokon untuk Rompi Tahan Peluru_. Jurnal Riset Industri Vol. 4 No.1: 1-12.

[12] Mudyantini Widya. (2008). _Pertumbuhan, Kandungan Selulosa, dan Lignin pada Rami_. Jurusan Biologi, Universitas Sebelas Maret. Biodiversitas. ISSN: 1412-033X, Vol. 9: 269-274.

[13] Purwanto, dkk. (2014). _Karacteristik Morfologi dan Struktur Mikro Serat Kenaf (Hibiscus Cannabinus L.) Akibat Perlakuan Kimia_. Proceeding Pertemuan Ilmiah XXVIII HFI Jateng & DIY. April 2014. Yogyakarta. ISSN: 0853-0823.

[14] Smole, S.M., et al. (2013). _Advances in Agrophysical Research_. In Tech, Kroasia. U.S. Department of Justice. (2000). Ballistic Resistance of Personal Body Armor NIJ Standard–0101.04. Washington, DC.

[15] Syam, R. dan Djafar, Z. (2012). _Analisis Sifat Mekanis Tenunan Serat Rami Jenis Basket Tipe S 3/12 dengan Matriks Epoksi Resin (Kekuatan Bending)_. Makassar: Jurusan Teknik Mesin Fakultas Teknik Universitas Hasanuddin.

[16] Du, Y., Yan, N., Kortschot, M.T. (2015). _The Use of Ramie Fibers as Reinforcements in Composites_. Canada: University of Toronto.