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Potential of natural fiber composite materials for bulletproof vest applications

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Abstract

The bulletproof vest material that is often used is a composite material. Composites are a mixture of two or more material elements, with different mechanical properties, which aim to obtain new materials that have better mechanical properties than the constituent materials. One alternative mixture of materials in composite materials is to use natural fibers as a substitute for kevlar fibers. In Indonesia, which has a tropical climate, natural fibers are very easy to obtain from various kinds of plants found in Indonesia. Along with the many plants obtained, a lot of waste is also produced because of this. So research was conducted on the utilization of the potential of natural fibers for alternative composites. With the experimental method, from the results of the experiment, the results obtained from the five natural fibers that have been discussed, namely pineapple leaf fiber, water hyacinth fiber, bark fiber, hemp fiber, and bamboo fiber, only pineapple leaf fiber has not met the National Institute of Justice (NIJ) standard, while the other four natural fibers have met the NIJ standard for bulletproof vests.

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Keywords: Natural fiber; composite for bulletproof vest; mechanical properties; ballistic test; composite alternatives

1. Introduction

One of the needs of Indonesian National Armed Forces (TNI) personnel in the battlefield in addition to weapons to fight, TNI personnel also need personal protective equipment, one of the personal protective equipment that is often used on the battlefield is a bulletproof vest. Inside the bulletproof vest, there is a material coating the body that aims to reduce the amount of kinetic energy generated due to projectile penetration [1].

The bulletproof vest material that is often used is a composite material. Composites are a mixture of two or more material elements, with different mechanical properties, which aim to obtain new materials that have better mechanical properties than the constituent materials. Mechanical properties that can be improved are strength, flexibility, and low density [2].

Composites also have their advantages when compared to other alternative materials, such as being stronger, lighter, economical, and environmentally friendly [3]. One of the alternative mixture materials in composite materials is to use natural fibers as a substitute for kevlar fibers. In Indonesia, which has a tropical climate, natural fibers are very easy to obtain from various kinds of plants found in Indonesia. Along with the many plants obtained, a lot of waste is also produced because of this. Nisa's research [4] explained the potential to recycle natural materials for composite mixtures in body armor applications. From this research, it is known that various kinds of natural materials can be utilized as waste to be used as an alternative composite for bulletproof vest applications.

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2. Research method

This research focuses on descriptive qualitative research collecting existing experimental results and concluding what is the best result to be applied to bulletproof vests, while the natural materials to be discussed include bamboo fiber, hemp fiber, bark fiber, water hyacinth fiber, pineapple leaf fiber.

For mechanical testing the standard used is ASTM and in ballistic tests using the National Institute of Justice (NIJ) 0108.01 Ballistic Resistant Protective Materials and NIJ 0101.06 Armor Protection Levels standards.

Table 1. NIJ Standard Ballistic Protection [1,13]

Level	NIJ Standard	Test Bullets	Bullets Mass (g)	Velocity (m/s)
I	0108.01	22 LRHV Lead	2.6	320
	0108.01	38 Special RN Lead	10.2	259
IIA	0101.06	9mm FMJ RN	8.0	373
	0101.06	0.40 s & W FMJ RN	11.7	352
II	0101.06	9mm FMJ RN	8.0	398
	0101.06	0.357 Magnum JSP	10.0	436
IIIA	0101.06	0.357 SIG FMJ FN	8.1	448
	0101.06	0.44 Magnum SJHP	15.6	436
III	0101.06	7.62mm NATO FMJ	9.6	847
IV	0101.06	0.30 Calibre M2 AP	10.8	878

3. Results and discussion

Results and discussion of the research that has been carried out, using experimental methods with mechanical tests and ballistic tests.

3.1 Pineapple Leaf Fiber (PLF)

One of the plants that thrive in Indonesia is pineapple fruit, the selling value of pineapple fruit in Indonesia is also very good, besides that, pineapple leaf waste has no selling value, so it can be called waste. The use of pineapple leaves itself has been much done, such as the use of pineapple leaf fibers for composite material mixtures.

Like the research conducted by Rahmatullah, et al (2021) [5] in this study, particle composites composed of epoxy with reinforcement in the form of Hollow Glass Microsphere (HGM) and pineapple leaf fibers were used. The same percentage of matrix volume ratio and fiber, namely pineapple fiber 10%, epoxy resin 74% and HGM 16%, using a size of 15x15x2cm^3, with thickness variations of 10 mm, 15 mm, and 20 mm. With NIJ standard level IIA testing standards for test ammunition of 9 mm FMJ, nominal bullet mass of 8.0 g, minimum required bullet of velocity 365 m/s.

Table 2. Mechanical Properties of Pineapple Leaf Fiber [6,15]

Properties	Tensile Strength (MPa)	Elongation (%)	Young's Modulus(GPa)	Hardness (HB)
Pineapple Leaf Fiber	126.60	2.2	4.405	20.41

From the test results of the test specimens in Figure 1 with thicknesses of 10 mm, 15 mm and 20 mm, the results show that the bullet can penetrate the specimen with penetration depth values of 58 mm, 10 mm and 4 mm, respectively. According to the NIJ 0101.06 standard, the bulletproof vest failure criteria seen from the penetration aspect should not exceed the thickness of the vest or should not penetrate the vest. It is concluded that pineapple leaf fiber still cannot meet the criteria to become an alternative material for bulletproof vests.

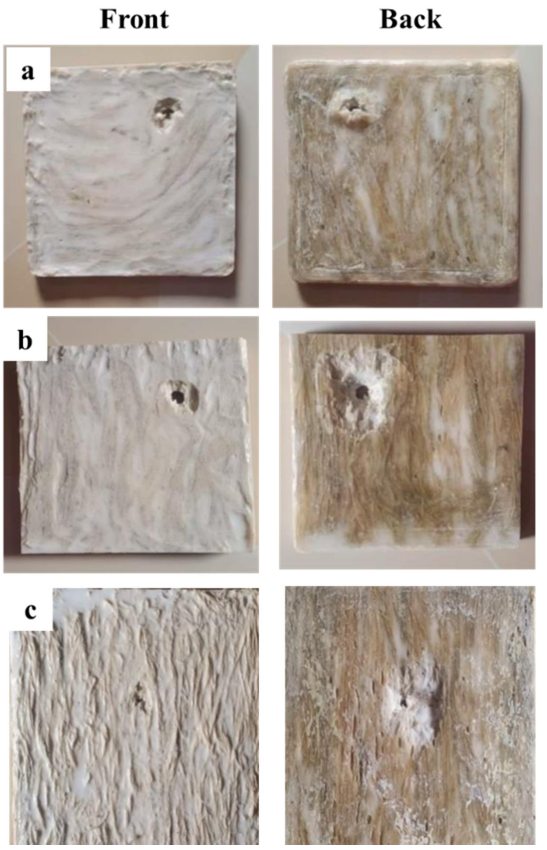


Figure 1. Ballistic Testing Results (a) 10mm Thickness (b) 15mm Thickness (c) 20mm Thickness [5]

3.2 Water Hyacinth Fiber (WHF)

Water hyacinth is a difficult-to-control aquatic weed that can live in rivers, swamps, and lakes. One alternative to utilizing it is as a composite material. In Hanafi's research (2020) [3] water hyacinth is utilized as an alternative material for bulletproof vest composites. This research uses a volume fraction of 30% fiber, 70% polyester, and a mold with a size of 15 x 15 cm thickness of 10 mm. The ballistic test used a 4.5 mm caliber angina rifle with a shooting distance of 5 m. There are 2 variations used, namely specimen 1 unidirectional and layered fiber arrangement, and specimen 2 vertical and horizontal layered fiber arrangement.

Tabel 3. Mechanical Properties of Water Hyacinth Fiber [7,14]

Properties	Tensile Strength (MPa)	Elongation (%)	Young's Modulus (GPa)	Hardness (HB)
Water Hyacinth Fiber	11.4	40.2	0.443	133

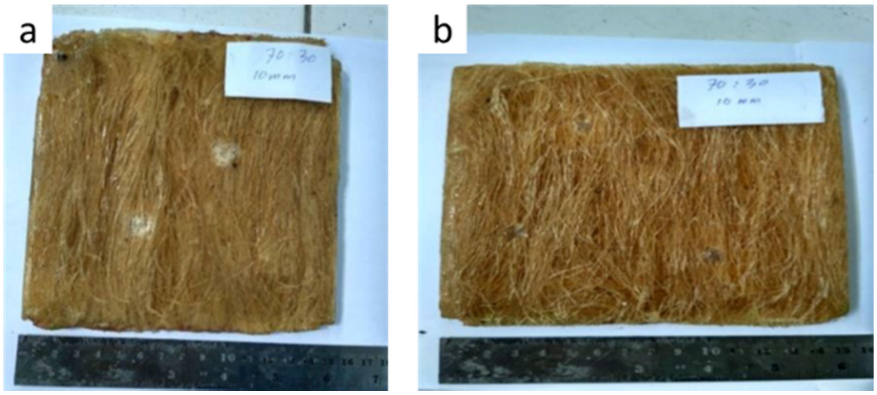


Figure 2. (a) vertical directional arrangement (b) vertical and horizontal multi-layered arrangement [3]

The results of ballistic testing on the test specimens, specimen 1 and specimen 2 have a panel condition that is not penetrated by bullets at a speed of 229.81 m/s at a distance of 5 m with a caliber of 4.5 mm. From these results, specimens 1 and 2 are included in the NIJ 0108.01 level I standard.

3.3 Bark Fiber

Similar to the previous salak is one of the fruits with high selling value in Indonesia, along with the salak fronds that are produced from each harvest into waste that has no selling value. One way to overcome this is by utilizing it as an alternative composite material for bulletproof vests. As in Kamal's research (2021) [8] this research uses volume fractions with specimen 1: 70% resin, 20% kevlar, 10% filler silicon carbide (SiC), silicon carbide (SiC) is a compound of silicon and carbon that when joined together forms an extremely hard ceramic that is widely used for applications that require high durability, such as car brakes, car clutches, and bulletproof vests, specimen 2: 70% resin, 10% filler (SiC), 10% salak frond fiber, 10% kevlar, specimen 3: 70% resin, 10% filler (SiC), 10% salak frond fiber, 10% kevlar and AL 7075. For ballistic tests using NIJ standard 0101.06 level IIA and II with distances of 5 m, 10 m, 25 m, and 30 m, with a firing speed of 373 m/s at a distance of 25 m, and 398 m/s at a distance of 5 m.

Tabel 4. Mechanical Properties of Bark Fiber [8]

Properties	Tensile Strength (MPa)	Elongation (%)	Young's Modulus (GPa)	Hardness (HB)
Bark Fiber	21.46	0.12	0.198	19.64



Figure 3. Specimen Ballistic Testing [8]

The results of ballistic testing of specimen 1 with a distance of 5 m and 10 m bullets penetrated the test specimen, while at a distance of 25 m and 30 m, the bullets fired did not penetrate the test specimen. It can be said that specimen 1 meets the NIJ level IIA standard. For specimen 2 from all testing distances the bullet successfully penetrated the test specimen, it can be said that specimen 2 does not meet the NIJ level IIA standard. As for specimen 3 at all distances the bullet did not penetrate the test specimen, so it can be said that specimen 3 meets the NIJ level IIA and II standards. It can be concluded that specimen 1: 70% resin, 10% filler silicon carbide (SiC) and 20% kevlar, complies with Standard NIJ level IIA and specimen 3: 70% resin, 10% filler (SiC), 10% salak frond fiber, 10% kevlar and AL 7075, meets Standard NIJ level IIA and II.

3.4 Hemp Fiber

One of the basic ingredients of bulletproof vests is glass fiber. In Indonesia glass fiber material is still obtained from abroad. To minimize imported materials to reduce costs and increase, one way to find materials to replace glass fiber with minimal costs but with the same function, one material that is alternative to glass fiber for bulletproof vests is hemp fiber. Hemp fiber is the basic material for making paper and clothing. The advantage of jute fiber compared to glass fiber is that it is more environmentally friendly and affordable. Like the research conducted by Setyawan (2020) [10] which examined hemp fiber for bulletproof vests. The study used a mixture ratio of 70% epoxy and 30% jute fiber with 4 variations, namely specimen 1 woven, specimen 2 horizontal, specimen 3 random specimens 4 tilted 45^{o} with a specimen size of 20 x 20 cm. For ballistic tests using the NIJ 0108.01 standard caliber 38, speed 259 m/s with a distance of 10 m.

Tabel 5. Mechanical Properties of Hemp Fiber [9]

Properties	Tensile Strength (MPa)	Elongation (%)	Young's Modulus (GPa)	Hardness (HB)
Hemp Fiber	310-750	2-4	20-41	84.6

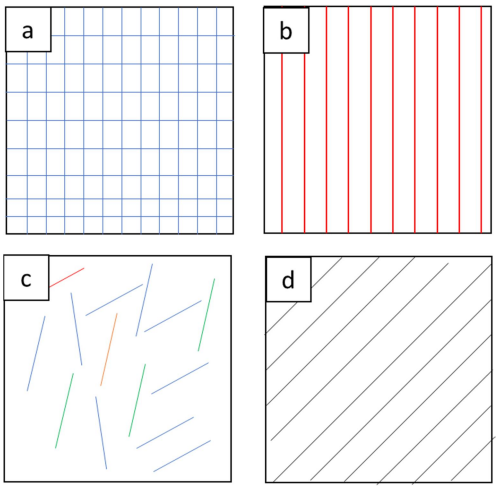


Figure 4. (a) Webbing Specimen 1 (b) Horizontal Specimen 2 (c) Random Specimen 3 (d) Sloping Specimen 4 [10]



Figure 5. Specimen After Ballistic Testing [10]

The results of ballistic testing using the NIJ 0108.01 standard includes bullet deformation and whether or not the specimen is penetrated when hit by a bullet. In ballistic testing of the 4 specimens, no bullets penetrated the specimen, with the best result being specimen 1 in the form of webbing. It can be concluded that hemp fiber meets the NIJ 0108.01 level I standard.

3.5 Bamboo Fiber

The main material in making bulletproof vest material is steel with a high density, so the weight of the bulletproof material is high which causes users to be unable to move freely. Composites are materials consisting of two or more elements that have good mechanical properties and low density, so they can be used as an alternative to steel for bulletproof materials. Arman (2022) utilizes bamboo fiber as a bulletproof material with a mixed matrix of epoxy resin/hardener and the addition of 20ml ceramic granules, with a 200mm x 100mm x 10mm mold. For ballistic testing using NIJ standard 0101.06 level IIA, with shooting distances of 2 m, 2.5 m, and 3 m.

Tabel 6. Mechanical Properties of Hemp Fiber Bamboo Fiber [12]

Properties	Tensile Strength (MPa)	Elongation (%)	Young's Modulus (GPa)	Hardness (HB)
Bamboo Fiber	206.2	29,2%	13.1	33

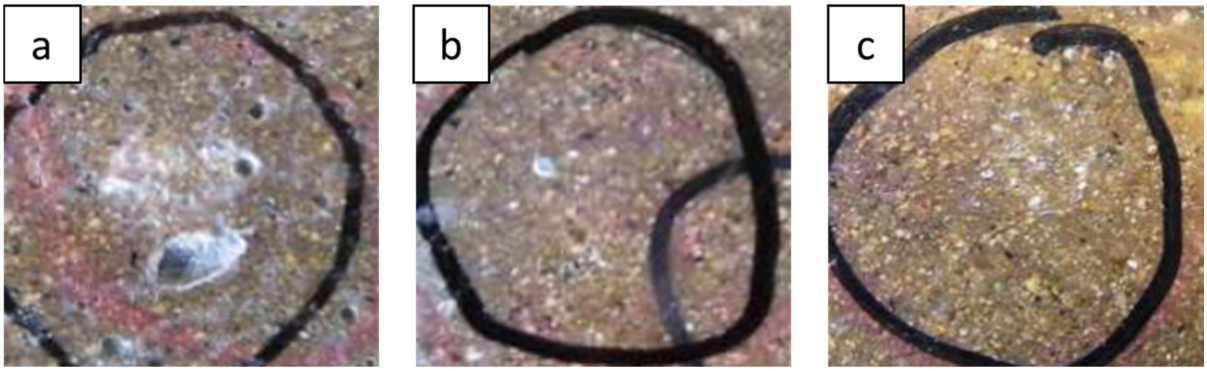


Figure 5. Bamboo Fiber Specimen After Ballistic Testing (a) 2 m (b) 2,5 m (c) 3 m [11]

From the ballistic test results, it can be seen in Figure 5 that none of the bullets penetrated the test specimens, so it can be concluded that the test results have met the NIJ 01.01.06 standard regarding the depth of ballistic penetration of composite materials.

3.6 Discussion

From the results of the data that has been obtained from the studies that have been carried out, the five natural fibers used for alternative composites for bulletproof vest applications can be categorized as follows:

Tabel 7. Classification of Natural Materials based on NIJ Standard [13]

Properties	Velocity (m/s)	NIJ Level	Reference
Pineapple Leaf Fiber (PLF)	365	-	Rahmatullah, et al (2021)
Water Hyacinth Fiber (WHF)	229.81	I	Hanafi, et al (2020)
Bark Fiber	398	IIA & II	Kamal, et al (2021)
Hemp Fiber	259	I	Setyawan, et al (2020)
Bamboo Fiber	373	IIA	Arman, et al (2022)

4. Conclusions

From the results of the research and discussion above, it can be concluded that the use of natural fibers for alternative composites has been widely carried out to minimize the waste produced, at the same time natural materials for alternative composites are cheaper and environmentally friendly. Of the five natural fibers that have been discussed, namely pineapple leaf fiber, water hyacinth fiber, salak frond fiber, hemp fiber, and bamboo fiber, only pineapple leaf fiber has not met the NIJ standard, while the other four natural fibers have met the NIJ standard for bulletproof vest. So that it can be applied to composite materials for making bulletproof vests for Indonesian National Armed Forces (TNI) personnel.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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