RiESTech

Recent in Engineering Science and Technology

MBI

Article

The Effect of 5wt.% and 10wt.% Salacca Frond Fiber Addition on Kevlar and Carbon Fiber Reinforced Epoxy using Vacuum Assisted Resin Transfer Molding (VARTM) Method for Bulletproof Vest Application

Vina Nanda Garjati [1,*], Vika Rizkia [1], Nur Agnes Aggraeni [1], Muslimin [1]

[1] Department of Mechanical Engineering, Politeknik Negeri Jakarta, Depok 16425, Indonesia
* Correspondence: vina.nanda@mesin.pnj.ac.id

Abstract: Bulletproof vests as self-protection for military personnel are generally made from synthetic fiber-reinforced composites. Kevlar and carbon fiber reinforced composites have been able to withstand bullet penetration rates and have lightweight characteristics, but production costs with synthetic fibers are relatively expensive. The use of substitute materials from natural fiber is very potential, due to the abundance of natural fiber, lightweight, and relatively cheap price. One of the potential natural fibers is fiber from the salacca midrib. This study focused on the effect of adding salacca frond fiber on the composite characteristics of Kevlar fiber and carbon fiber, with SiC and Al2O3 fillers. The manufacture of this composite is carried out by the Vacuum Assisted Resin Transfer Molding (VARTM) method. There are 4 variations of fiber volume fractions and fillers as reinforcement added to this composite. From the results of observations with SEM, the results of the matrix and reinforcement are well bound. The ballistic test results show that all variations of test samples can withstand the bullet rate so that it does not penetrate. The results of mechanical tests show that currently the addition of salacca frond fiber has not significantly improved the mechanical properties of the composite

Keywords: Composite; Natural Fiber; Sallaca Frond Fiber; VARTM; Bulletproof Vests

Citation:. Garjati, V. N., Vika Rizkia, Aggraeni , N. A., & Muslimin. (2023). The Effect of 5wt.% and 10wt.% Salacca Frond Fiber Addition on Kevlar and Carbon Fiber Reinforced Epoxy using Vacuum Assisted Resin Transfer Molding (VARTM) Method for Bulletproof Vest Application. Recent in Engineering Science and Technology, 1(03), 45–55. https://doi.org/10.59511/riestech.v1i03.27

Academic Editor: Iwan Susanto

Received: 9 June 2023
Accepted: 26 June 2023
Published: 1 July 2023

1. Introduction

A bulletproof vest is the most common ballistic protection instrument used by military personnel. The ability to have high mobility and effective protection are the main characteristics required for the use of a bulletproof vest[1]. In order to fulfill the function of withstanding penetration and minimizing the impact energy from projectiles, selecting appropriate materials is crucial. Initially, bulletproof vests used in World War I & II were made of metal. However, these vests had the disadvantage of being heavy, which could hinder the mobility of military personnel[2]. This issue has encouraged innovation and curiosity in synthetic composite materials research, which are Kevlar and carbon.

The use of Kevlar fibers in composites has a significant impact on the tensile strength properties. Being incredibly strong and durable, Kevlar fibers have been widely used in various composite applications such as boats, airplanes, racing cars, and even protective clothing. Kevlar fibers are renowned for their high strength, stiffness, and resistance to wear. In composites, Kevlar fibers are typically used as reinforcement to enhance their tensile strength. This is possible because Kevlar fibers can withstand high tensile forces, reducing the risk of material failure and improving the durability and safety of the composite[2]. During the composite production process, Kevlar fibers can be combined with other materials such as carbon fibers or glass fibers to reinforce the composite. However, the use of Kevlar fibers also has its drawbacks. Kevlar fibers are more expensive than other fibers, leading to higher composite production costs. Additionally, Kevlar fibers exhibit different thermal properties compared to other base materials in the composite, requiring careful consideration during the design and production process[2].

Kevlar and carbon fibers reinforced composites have adequately met the primary criteria for bulletproof vests, which require lightweight and strong materials[3][4]. The utilization of Kevlar fibers in composites can enhance their tensile strength, yet cost and thermal properties must also be taken into account. Therefore, careful calculations and adjustments are necessary to ensure that Kevlar fibers can provide optimal benefits for the composite products.

Due to the abundance and relatively low cost of natural fibers, various research have been developed to study the replacement of synthetic fibers with natural fibers in composite fabrication[5][6][7]. Moreover, these fibers possess low density and reasonably good mechanical properties for application in bulletproof vests[8].

Ning, H. reported that embedding kenaf fibers in polyethylene composites demonstrated a significant increase in tensile strength[9]. A.M.R Azmi performed ballistic tests on the same material, but the results indicated the need for further improvement in material quality to fully withstand bullet penetration[10].

The potential natural fiber for substituting synthetic fibers is Salacca frond fibers, which are extracted from salacca tree. The salak fruit tree is a tropical plant abundant in Indonesia, particularly in the Special Region of Yogyakarta. Various studies have been conducted regarding salacca frond fibers in Indonesia. Yudha, et al., have successfully isolated cellulose from the rachis of the salak fruit tree to produce salacca frond fibers[11][12]. However, further research on the effects of salacca frond fibers as reinforcement in composites for bulletproof vest applications is highly needed. Thus, this study focuses on the manufacturing and analysis of epoxy resin composites reinforced with salacca frond fibers, carbon fibers, and Kevlar fibers, using SiC and Al2O3 fillers through the Vacuum Assisted Resin Transfer Molding (VARTM) method.

2. Materials and Experiment Methods

The composite plates in this research were produced through the Vacuum Assisted Resin Transfer Molding (VARTM) method with symmetrical fiber orientation[13][14]. Several modifications were made to the VARTM method by adding a rigid mold at the top to achieve a smooth surface finish on the upper part and to obtain the desired thickness while ensuring a smooth distribution of resin into the mold. The dimensions of the composite molds used were 25 x 25 x 2 cm, 25 x 25 x 0.25 cm, and 20 x 15 x 1.27 cm. The sequence of fiber arrangement, in consecutive order, was Kevlar fibers with Al_2O_3 filler, salacca frond fibers, carbon fibers, salacca frond fibers, and Kevlar fibers with SiC filler. The four variations of fiber additions in this study are presented in Table 1.

Subsequently, adhesive was sprayed, and all laminate surfaces were covered to ensure airtightness. Then, the resin was injected into the mold, and the samples were left to cure. Characterization performed on the composite samples in this study included impact testing (ASTM D6110-10), tensile testing (ASTM D3039), hardness testing, Scanning Electron Microscope (SEM) analysis, and ballistic testing following the NIJ 0101.06 Level II standard. Ballistic testing was conducted using 9 mm caliber ammunition (MU-1TJ) with a mass of 8 grams and an average velocity of 380 m/s. Additionally, ballistic tests were conducted using 5.56 mm caliber ammunition (MU5-TJ) with a mass of 4 grams and an average velocity of 915 m/s.

Table 1. Variation of fiber in the composite

No.	Salacca Frond Fiber (%)	SiC Filler (%)	Al_2O_3 Filler (%)	Carbon Fiber (%)	Kevlar Fiber (%)
1	10	5	5	10	10
2	5	5	5	10	15
3	2.5	7.5	7.5	2.5	20
4	2.5	5	5	2.5	25

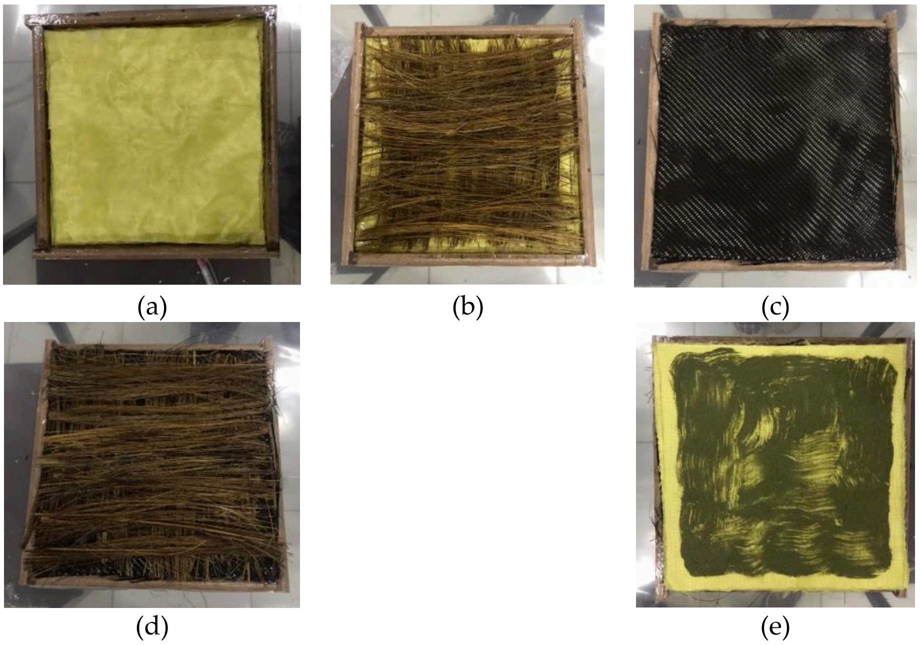


Figure 1. composite fiber arrangement in the mold: (a) Kevlar fibers, (b) salacca palm fibers, (c) carbon fibers, (d) second layer of salacca frond fibers, and (e) Kevlar fibers with Al_2O_3 filler as the top layer

3. Results and Discussion

3.1 Tensile Test Analysis

Tensile testing was performed on 5 specimens for each sample variation. The average tensile strength values of all specimens for each fiber addition variation are depicted in Figure 2. As can be seen, the 1st variation showed the lower tensile test value of 148.59 N/mm^2. Meanwhile, the 4th variation reached the highest tensile test value of 177.91 N/mm2.

Based on the test results, 1st variation with the highest addition of salacca frond fiber of 10wt.%, and the lowest addition of Kevlar fibers of 10wt.%, exhibited the lowest tensile strength compared to the other four variations. On the other hand, 4th variation with the lowest addition of salacca frond fibers of 2.5wt.%, and the highest addition of Kevlar fibers of 25wt.%, showed the highest tensile strength among the four variations.

Tensile strength is greatly influenced by the constituent materials, in this research, the composition of the fiber reinforcements. The significant improvement in tensile strength is attributed to the addition of Kevlar fibers, while the effect of salacca frond fibers addition on enhancing the tensile strength of the material is not yet apparent.

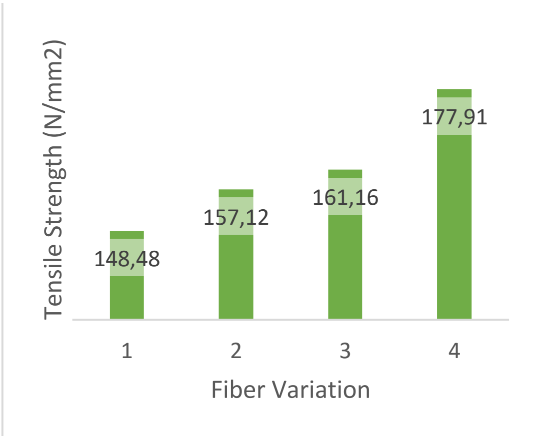


Figure 2. Comparison of Tensile Strength value for all variations

3.2 Hardness Test Analysis

Hardness testing was conducted using the Rockwell method on the F scale with a 1/16-inch indenter size and a force of 60 kgf. The testing involved indenting 5 points on each sample. The average hardness values for all indentations in this research are shown in Figure 3. Figure 3 depicts that the 1st variation showed the lowest hardness test value of 23 HRF. Meanwhile, the 4th variation yielded the highest hardness test value of 49.8 HRF.

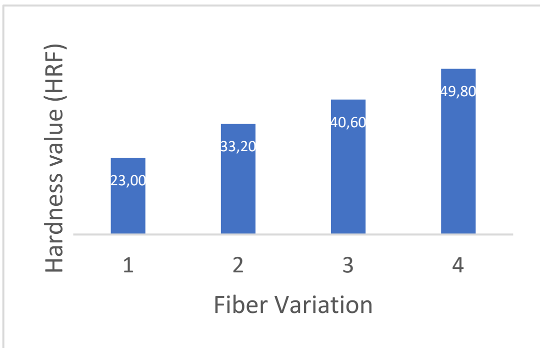


Figure 3. Comparison of hardness value for all variations.

The variation with the highest addition of salacca frond fiber (10wt.%) and the lowest addition of Kevlar fibers (10wt.%) had the lowest hardness value compared to the other four variations. In contrast, the fourth variation with the lowest addition of salacca frond fibers (2.5wt.%) and the highest addition of Kevlar fibers (25wt.%) exhibited the greatest hardness value among the four variations. This phenomenon is due to during the hardness testing, the tested part is the upper portion composed of SiC and Kevlar fibers. The significant increase in hardness value is predominantly due to the effect of adding Kevlar fibers into the composites.

3.3 Impact Test Analysis

All of the impact test specimens in this research followed the ASTM D 6110-10 standard. The average Impact Strength (IS) values of all fiber variations are presented in Figure 4. Each sample variation consists of 5 (five) impact specimens. Based on Figure 4, it is clearly seen that the average impact strength for the first variation is 0.19 J/mm^2, while the impact strength for the second variation is 0.18 J/mm^2.

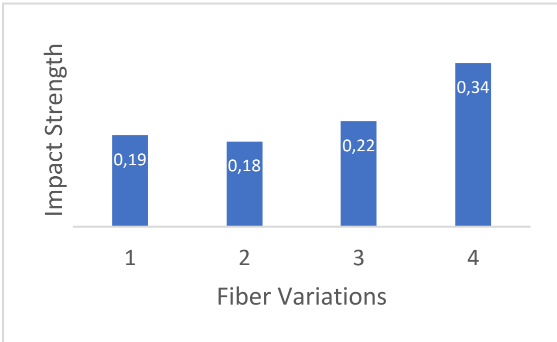


Figure 4. Comparison of impact strength value for all variations.

A higher content of salacca frond fibers will increase the impact resistance of the composite material. This phenomenon is related to the presence of a strong bond between the salacca frond fibers and the matrix, allowing for even energy transfer throughout the fibers. Therefore, an increased amount of salacca frond fibers will result in higher resistance to impact loading. The average impact strength for the third variation is 0.22 J/mm^2, while the impact strength for the fourth variation is 0.34 J/mm^2. The increase in Impact Strength (IS) with the increasing amount of Kevlar fibers in this composite indicates that the Kevlar fiber composition affects the impact strength of materials, whereas a higher Kevlar fiber content enhances the composite material's resistance to impact loading.[15]

3.4 Morphological Analysis

Microstructure observations were conducted using a Scanning Electron Microscope to examine the bond between the matrix and the reinforcement. Based on Figure 5, for the 1st and 2nd variations, debonding (bond detachment failure) is observed. However, the matrix (resin) and reinforcement (fibers) of both specimens are well-bonded as can be seen in Figure 5(a) and (b). In the 3rd variation, fiber pull-out (failure of fibers being pulled out) is observed in Figure 6(c), which results in the separation of the reinforcement component from the matrix component. On the other hand, the matrix (resin) and reinforcement (fibers) are well bonded for the 4th specimen[16].

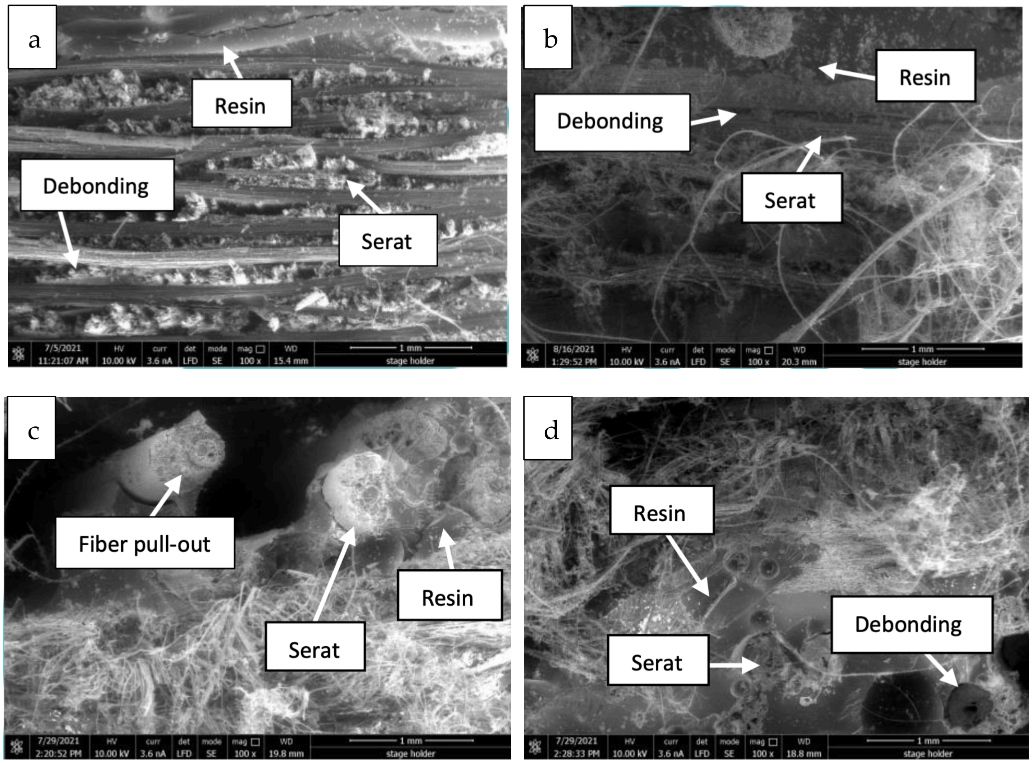
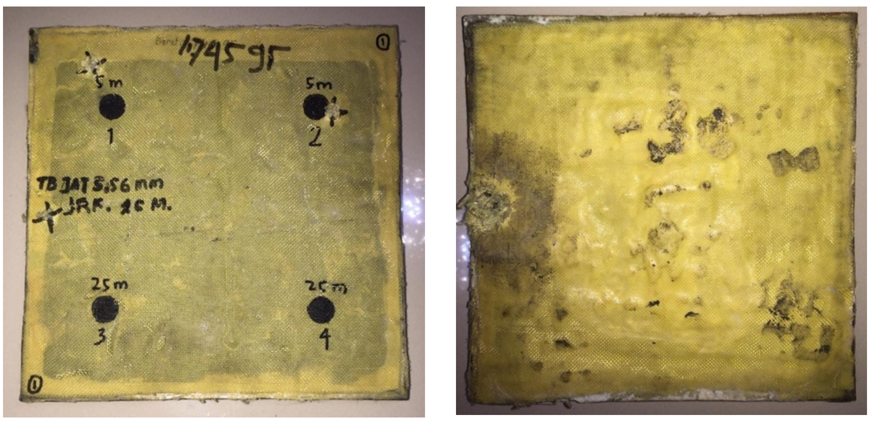


Figure 5. SEM images for all variations (a) 1st variation, (b) 2nd variation, (c) 3rd variation, and (d) 4th variation

3.5 Ballistic Test Analysis

First Variation

The composite material composed of 60% resin, 10% salacca frond fibres, 5% SiC filler, 5% Al_2O_3 filler, 10% carbon fibers, and 10% Kevlar fibers was subjected to ballistic testing using 9 mm caliber ammunition and a P1 Pindad gun at a distance of 5 meters, following NIJ 0101.06 Level II standards. The obtained Back Face Signature (BFS) for 1st variation was 3.79 mm. Since this value is still far below 44 mm, it is very safe and meets Level IIA and II specifications.



(a) (b)

Figure 6. The ballistic test results for 1st variation (a) Front View, and (b) Back view

Therefore, further testing needs to be conducted for the next level. Level III testing was performed using 5.56x45 mm caliber ammunition, an SS1 rifle, and a distance of 25 meters. The composite material was shot at the lower left part. The result obtained was penetration because it couldn't withstand the impact when the bullet hit, which means it is not safe and doesn't pass the Level III requirements. The ballistic test results can be seen in Figure 6(a) and (b).

Second Variation

The composite material composed of 60% resin, 5% salacca palm fibres, 5% SiC filler, 5% Al_2O_3 filler, 10% carbon fibers, and 15% Kevlar fibers was subjected to ballistic testing using 9 mm ammunition and a P1 Pindad gun at a distance of 5 meters, in accordance with NIJ 0101.06 Level II specifications. The obtained result was non-penetration with a BFS of 9.18 mm, as this BFS value is still well below 44 mm, indicating it is very safe and meets Level IIA and II specifications. Therefore, additional assessment is required for the next level. The level III ballistic testing results are penetrable because the object cannot withstand the impact of the bullet, indicating that it is not secure and does not qualify for level III.

Based on previous research conducted by J. Naveen et al, the natural fiber-based bulletproof vest has a lower indentation depth compared to the Kevlar fiber-based bulletproof vest[17].

The current study shows that the composition of salak frond fiber greatly affects the ballistic strength of the material, where the higher the content of salak frond fiber (in this case from 5% to 10%) will increase the resistance of the composite material to firing loading. This is evidenced by specimens with 10% salak frond fiber content having a minimal BFS of 3.79 mm compared to specimens with 5% salak frond fiber content having a BFS of 9.18 mm. Bulletproof vest materials with more composition of salak frond fibers have lower depth indentation results. In other words, the bulletproof material with lower composition of salak frond fibers obtained 58% higher BFS, but still below the required limit according to the standard of 44 mm[18]. The presence of natural fibers in the form of salak frond fibers in variations 1 and 2 is certainly able to reduce the use of synthetic fibers (kevlar fibers) so that of course it will also reduce production costs where kevlar fibers have a fairly expensive price.

These two specimens succeeded as NIJ level II and IIA standard bullet resistant materials, where the BFS determined according to this NIJ standard is 44 mm. With BFS results that are still far from 44 mm, it is possible that this material will also succeed at level IIIA because it uses a velocity of 430 m/s where the velocity is not too far away from level II of 379 m/s, so it is recommended that further research be carried out with level IIIA testing. Level III testing has also been carried out using a long-barreled shotgun with the results of all specimens penetrating.

The weight of the specimen with a composition of 10% salak frond fiber and 10% kevlar fiber is 1,877.5 g while the weight of the specimen with a composition of 5% salak frond fiber and 15% kevlar fiber is 1,898.7 g, so that from this composition the specimen with the best ballistic ability has a smaller weight. This is also very efficient for troop mobility when using bulletproof vests.

The results of this ballistic test have a relationship with the results of impact resistance, where specimens that have good ballistic resistance also have good impact resistance.

Third Variation

The composite material composed of 60% resin, 2.5% salak frond fiber, 7.5% SiC filler, 7.5% Al2O3 filler, 2.5% carbon fiber and 20% kevlar fiber were ballistically tested using 9 mm caliber and Pindad P1 pistol with a distance of 5 m referring to NIJ 0101.06 Level II. The results obtained are not penetrated with a BFS of 7.10 mm, because the BFS results obtained are still far from 44 mm which means it is very safe and passes at levels IIA and II. Therefore, additional assessment is required for the next level. The level III ballistic testing results are penetrable because the object cannot withstand the impact of the bullet, indicating that it is not secure and does not qualify for level III.

Fourth Variation

The composite material composed of 60% resin, 2.5% salak frond fiber, 5% SiC filler, 5% Al2O3 filler, 2.5% carbon fiber and 25% kevlar fiber were ballistically tested using a 9 mm caliber and a P1 Pindad pistol with a distance of 5 m which refers to NIJ 0101.06 Level II. The results obtained are not penetrated with a BFS of 6.48 mm, because the BFS results obtained are still far from 44 mm which means it is very safe and passes at levels IIA and II, so it is necessary to test to the next level, namely IIIA but due to limited munitions, testing is carried out to two levels above it, namely level III with a caliber of 5.56x45 mm, SS1 rifle and a distance of 25m. The composite was fired at the top right. The result obtained is penetrated because it cannot withstand the impact when the bullet hits, which means it is not safe and does not qualify for level III.

Based on previous research conducted by Deepak M.V.S et al, it is stated that the addition of ceramic fillers such as SiC and Al_2O_3 to kevlar fibers results in an increase in impact strength values if the composition of kevlar fibers is constant. Kevlar fibers are usually resistant to impact and can resist propagating cracks[19].

The current study shows that when making changes by varying kevlar fibers as well as ceramic fillers (SiC and Al_2O_3), kevlar fibers greatly affect the ballistic strength of the material, where the higher the kevlar fiber content (in this case from 20% to 25%) will increase the resistance of the composite material to firing loading. This is evidenced by specimens with 25% kevlar fiber content having a minimal BFS of 6.48 mm compared to specimens with 20% kevlar fiber content having a BFS of 7.10 mm. Bulletproof vest materials with more kevlar fiber composition have lower depth indentation results. In other words, bullet-resistant materials that have a low kevlar fiber composition obtained 8.73% higher BFS results, but still below the required limit according to the standard of 44 mm. The presence of SiC and Al_2O_3 ceramic fillers can certainly reduce the use of kevlar fibers.

These two specimens succeeded as NIJ level II and IIA standard bullet resistant materials, where the BFS determined according to this NIJ standard is 44 mm. With BFS results that are still far from 44 mm, it is possible that this material will also succeed at level IIIA, so it is recommended that further research be carried out with level IIIA testing. Level III testing has also been carried out using a long-barreled rifle with the results of all specimens penetrating.

The weight of the specimen with a composition of 15% ceramic filler (SiC and Al_2O_3) and 20% kevlar fiber is 2018.7 g while the weight of the specimen with a composition of 10% ceramic filler (SiC and Al_2O_3) and 25% kevlar fiber is 1,885 g, so from this composition the specimen with the best ballistic ability has a smaller weight. This is also very efficient for troop mobility when using bulletproof vests.

The results of this ballistic test have a relationship with the results of impact resistance, where specimens that have good ballistic resistance also have good impact resistance.

4. Conclusions

Based on the results of the analysis that has been carried out, the conclusions that can be drawn are:

a. The Vaccum Assisted Resin Transfer Molding (VARTM) method with a third mold is the best modification because it results in faster resin distribution and manufacturing.
b. The impact strength, tensile strength, hardness, microstructure and ballistic capability of variations 1, 2, 3, and 4 were obtained as follows:
   - The impact strength value in variation 1 (60% resin, 10% salak frond fiber, 5% SiC filler, 5% Al2O3 filler, 10% carbon fiber and 10% kevlar fiber) is 0.19 J/mm², while in variation 2 (60% resin, 5% SiC filler, 5% Al_2O_3 filler, 5% salak frond fiber, 10% carbon fiber and 15% kevlar fiber) is 0.17 J/mm². So variation 1 has an impact strength 10.5% greater than variation 2. The impact strength value in variation 3 (60% resin, 7.5% SiC filler, 7.5% Al_2O_3 filler, 2.5% salak frond fiber, 2.5% carbon fiber and 20% kevlar fiber) is 0.22 J/mm², while in variation 4 (60% resin + 5% SiC filler + 5% Al_2O_3 filler + 2.5% salak frond fiber + 2.5% carbon fiber + 25% kevlar fiber) is 0.34 J/mm². So variation 4 has an impact strength 35.3% greater than variation 3.
   - The hardness value in variation 1 is 22.72 HRF, while the hardness value in variation 2 is 33.12 HRF. So that variation 2 has a hardness 31.4% greater than variation 1. The hardness value in variation 3 is 40.52 HRF, while the hardness value in variation 4 is 49.56 HRF. So that variation 4 has a hardness 18.24% greater than variation 1.
   - The tensile strength value in variation 1 was 148.59 N/mm², the strain was 0.04% and the elastic modulus was 3746.81 N/mm².The tensile strength of variation 2 was 246.93 N/mm², the strain was 0.06% and the elastic modulus was 4355.9 N/mm².So that variation 2 has a tensile strength 39.8% greater than variation 1. While the tensile strength value in variation 3 is 161.16 N/mm², the strain is 0.04% and the elastic modulus is 3779.98 N/mm².The tensile strength value of variation 4 was 177.91 N/mm², strain of 0.06%, elastic modulus of 3190.45 N/mm². So variation 4 has a tensile strength 9.41% greater than variation 3.
   - The BFS results in variation 1 amounted to 3.79 mm with a weight of 1877.5 g, while in variation 2 amounted to 9.18 mm with a weight of 1898.75 g. The BFS values of variations 1 and 2 have met the requirements of the NIJ level II standard,

namely u < 44 mm.BFS results in variation 3 amounted to 7.10 mm, while in variation 4 amounted to 6.48 mm. The BFS values of variations 3 and 4 have met the requirements of the NIJ level II standard. So from variations 1, 2, 3 and 4 the best is variation 4 because it has a smaller weight and BFS value that is still safe.

- SEM test results from variations 1,2,3,4 show that the matrix (resin) and reinforcement (fiber) have bonded well.

Acknowledgments: I am sincerely grateful to Ahmad Adifani and Vernida Mufida for his continuous support and assistance in this research. I would also like to express my heartfelt gratitude to PT Badak NGL academy for their valuable collaboration with PNJ research and teamwork.

References

1. NIJ Standard-0101.06, "Ballistic Resistance of Personal Body Armor," *NIJ Stand.*, p. 89, 2008.
2. L. Lakshmi and C. G. Nandakumar, "Investigations on the Performance of Metallic and Composite Body Armors," *Procedia Technol.*, vol. 25, no. Raerest, pp. 170–177, 2016, doi: 10.1016/j.protcy.2016.08.094.
3. P. K. Mallick, *Materials, Manufacturing, and Design, Third Edition*. 2007.
4. A. B. M. Azhar, M. S. Risby, A. S. M. Sohaimi, M. N. Hafizi, S. Khalis, and S. Asrul, "Conceptual mold design for multi-curved natural fiber reinforced composite body armor panel," *Procedia CIRP*, vol. 37, pp. 95–100, 2015, doi: 10.1016/j.procir.2015.08.017.
5. D. A. N. Serat, K. Dalam, and M. Energi, "Analisis Kemampuan Rompi Anti Peluru Yang Terbuat Dari Komposit Hgm-Epoxy," 2017.
6. S. Rajesh, B. V. Ramnath, and K. O. Praveen, "EasyChair Preprint Experimental Investigation of Mechanical and Machining Characteristics of Aramid-Natural Fiber Composite," 2020.
7. R. Stopforth and S. Adali, "Experimental study of bullet-proofing capabilities of Kevlar, of different weights and number of layers, with 9 mm projectiles," *Def. Technol.*, vol. 15, no. 2, pp. 186–192, 2019, doi: 10.1016/j.dt.2018.08.006.
8. A. M. R. Azmi, M. T. H. Sultan, A. Hamdan, A. F. M. Nor, and K. Jayakrishna, "Flexural and Impact Properties of A New Bulletproof Vest Insert Plate Design Using Kenaf Fibre Embedded with X-Ray Films," *Mater. Today Proc.*, vol. 5, no. 5, pp. 11193–11197, 2018, doi: 10.1016/j.matpr.2018.01.143.
9. A. M. R. Azmi, M. T. H. Sultan, M. Jawaid, and A. F. M. Nor, "A newly developed bulletproof vest using kenaf-X-ray film hybrid composites," *Mech. Phys. Test. Biocomposites, Fibre-Reinforced Compos. Hybrid Compos.*, pp. 157–169, 2018, doi: 10.1016/B978-0-08-102292-4.00009-6.
10. N. M. Nurazzi *et al.*, "A review on natural fiber reinforced polymer composite for bullet proof and ballistic applications," *Polymers (Basel).*, vol. 13, no. 4, pp. 1–42, 2021, doi: 10.3390/polym13040646.
11. V. Yudha, H. S. B. Rochardjo, J. Jamasri, R. Widyorini, F. Yudhanto, and S. Darmanto, "Isolation of cellulose from salacca midrib fibers by chemical treatments," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 434, no. 1, 2018, doi: 10.1088/1757-899X/434/1/012078.
12. A. Pérez, "No 主観的健康感を中心とした在宅高齢者における 健康関連指標に関する共分散構造分析Title," *BMC Public Health*, vol. 5, no. 1, pp. 1–8, 2017, [Online]. Available: https://ejournal.poltektegal.ac.id/index.php/siklus/article/view/298%0Ahttp://repositorio.unan.edu.ni/2986/1/5624.pdf%0Ahttp://dx.doi.org/10.1016/j.jana.2015.10.005%0Ahttp://www.biomedcentral.com/1471-2458/12/58%0Ahttp://ovidsp.ovid.com/ovidweb.cgi?T=JS&P.
13. M. Hancioglu, E. M. Sozer, and S. G. Advani, "Comparison of in-plane resin transfer molding and vacuum-assisted resin transfer molding 'effective' permeabilities based on mold filling experiments and simulations," *J. Reinf. Plast. Compos.*, vol. 39, no. 1–2, pp. 31–44, 2020, doi: 10.1177/0731684419868015.

14. C. Polowick, *Optimizing Vacuum Assisted Resin Transfer Moulding (VARTM) Processing Parameters to Improve Part Quality*, no. April. 2013.
15. P. Priyanka, A. Dixit, and H. S. Mali, "High strength Kevlar fiber reinforced advanced textile composites," *Iran. Polym. J. (English Ed.*, vol. 28, no. 7, pp. 621–638, 2019, doi: 10.1007/s13726-019-00721-7.
16. W. D. Callister Jr and D. G. Rethwisch, *Characteristics, Application, and Processing of Polymers*. 2018.
17. J. Naveen, K. Jayakrishna, M. T. Bin Hameed Sultan, and S. M. M. Amir, "Ballistic Performance of Natural Fiber Based Soft and Hard Body Armour- A Mini Review," *Front. Mater.*, vol. 7, no. December, pp. 1–6, 2020, doi: 10.3389/fmats.2020.608139.
18. F. S. da Luz, F. da C. G. Filho, M. S. Oliveira, L. F. C. Nascimento, and S. N. Monteiro, "Composites with natural fibers and conventional materials applied in a hard armor: A comparison," *Polymers (Basel).*, vol. 12, no. 9, pp. 1–13, 2020, doi: 10.3390/POLYM12091920.
19. D. Mvs, K. M. Subbaya, T. S. R, A. Chikkala, P. K. Veera Gowda, and S. S. Almos, "Impact Behavior of Hybrid Nano Filled Kevlar Reinforced Composites," no. June, pp. 456–458, 2020.