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BODY ARMOR PROTOTYPE DESIGN USING ARAMID FIBRE (KEVLAR) COMPOSITE WITH ADDITIVES NANO TITANIUM DIOXIDE (TiO_2)

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ABSTRACT

Body armor has a function to resist penetration and reduce impact power generated by projectiles and expand the contact area between the bullet and the body. Aramid fiber is a type of heat-resistant synthetic fiber that has the characteristics of high strength and stiffness but has an expensive price that requires special studies in determining the effective number of fiber layers. The problems and objectives raised in this study are how the effect of aramid fiber layer arrangement with TiO_2 additives, and epoxy resin on ballistic body armor properties, the impact resistance of body armor specimens with the variable number of layers, material resistance to Charpy impact tests and bending tests, and how to design composite specimens that are effective and efficient and resistant to gunfire. The research method used is an experiment in making body armor specimens and then testing them to find out which layer is the most effective. From the specimens that have been made, there are 14, 16, 18, and 20 it is known that layers with 20 are the most effective layers. This can happen because, during ballistic impact testing, Charpy, Bending, Brinell, and Durometer this layer produces better values than others so it can be concluded that the number of layers affects the strength of the body armor.

Keywords: *Body Armor*, Charpy, Kevlar, aramid fiber, titanium dioxide

1. INTRODUCTION

Body armor serves to reduce and diminish the impact energy generated by projectile bullets, as well as to expand the contact area between the body and the bullet. It also helps to decrease penetration resulting from impact energy. In the event of a collision, the kinetic energy of the bullet is absorbed by the body armor and distributed across the protective plate area of the bulletproof vest. The remaining energy is then directed towards the wearer's body.

The utilization of high-strength technical fibers as reinforcement composites in body armor offers several advantages compared to conventional materials. These advantages include low density, flexibility, high rigidity, and good impact resistance. Aramid fibers are a type of heat-resistant synthetic fiber with distinct characteristics, including high strength and rigidity. However, in economic terms, aramid fibers are expensive and require specialized study to determine the optimal number of fiber layers needed to achieve optimal ballistic impact properties.

Cenk Yanen & Murat Yavus Solmas conducted ballistic impact testing using composite fiber materials of three types: aramid fiber, carbon fiber, and fiberglass, each consisting of 7 layers. Thus, the total layers in one specimen amounted to 21 layers, with variations in fiber direction and angle. The test results indicated that composites with fibers oriented in the same direction exhibited superior ballistic performance compared to other composites. Referring to this journal, in the writing of this thesis, the author employs a single type of fiber, namely aramid, with the same 21-layer configuration, and introduces variable composition of Titanium Dioxide (TiO2) Nano Particles as a filler or resin reinforcement in hopes of achieving better ballistic impact test results than the aforementioned research.

The method used is the Charpy Impact Test, which is commonly employed due to its higher accuracy of results, ease of testing, generation of uniform stress along the cross-section, and shorter required time. During the implementation of the impact test for composite specimens, the dimensions adhere to the parameters set by the American Standard Testing and Material. These specifications dictate a specimen length of 55 mm, width of 10 mm, and height of 10 mm, with a notching angle of 45 degrees and a notch depth of 2 mm.

In this study, the author utilizes Titanium Dioxide (TiO2) Nano Particles, which have the potential to be employed as fillers in the production of body armor specimens due to their anti-bacterial properties, ability to reinforce microstructure, mechanical characteristics, as well as during operational treatment of a composite specimen.

2. LITERATURE REVIEW

In the Brinell test, the lowest HB value was observed in specimen A0 at 10.40, while the highest value was recorded in specimen A15 at 13.26. For the Bending test, the lowest strength was found in A0 at 60.52 N/mm², and the highest strength was achieved in A15 at 71.90 N/mm². Therefore, specimen A15 meets the requirements to be considered as an alternative material for bulletproof vests. (Utomo, 2021).

The mechanical properties of the composite experience enhancement in terms of elongation and impact strength as carbon fibers undergo electro-polymerization with MMA or aniline. However, there is a decrease in tensile strength values. Nevertheless, the tensile strength value for the bulletproof vest SK/epoxy surpasses that of the aramid/epoxy/Al2O3 powder bulletproof vest. This makes it suitable for application under NIJ standards of Type IIA and II. (Ramadhanu, 2018).

The shear strength of laminar sample K285 exhibits a higher total Interglobal Laminar Shear (ILS) value compared to sample K120. The total ILS value of the samples is influenced by the type of resin and the quantity of fibers used. As both samples K285 and K120 in this study employ the same resin type and hardener (hardener), the effect of the fibers plays a role in determining the ILS value. Sample K120 has a fiber negative value of 195, while sample K285 has a negative value of 1140. A high negative value indicates that the sample's filaments are denser, leading to stronger adhesive forces between the laminar fibers. (Istanta, Analysis of The Effect Of Fiber Texture On The Physical And Mechanical Properties Of Aramid Epoxy Prepreg, 2020).

Laminated composite (reinforcements of sheets, paper, fabric, adhered and impregnated). (Isran, 2018). A composite is a structural material composed of two or more elements combined at the macroscopic level and not soluble in each other. One element is referred to as the reinforcement, while the other element that functions as the binder is called the matrix. The reinforcement element can take the form of fibers, particles, or fragments. Examples of composite materials include concrete reinforced with steel, epoxy reinforced with graphite fibers, and others (Kaw, 2007). Advantages and disadvantages of composite materials, as with other materials, Composite materials have their own strengths and weaknesses (Schwartz, 1997).

The matrix, as a space-filling component of the composite, plays a crucial role in transferring stress, shielding fibers from the environment, and preserving the fiber surface from erosion. The matrix should have good compatibility with the fibers (Moncrieff, 1975). Gibson (1994) states that the matrix in composite structures can be composed of polymer, metal, or ceramic materials. In general, the matrix functions to bind the fibers into a single composite structure.

During the molding process, this resin does not require pressure, as it has relatively low viscosity while still in a liquid state. It solidifies at room temperature with the use of a catalyst without generating gas (unlike other thermoset resins). Generally, this resin exhibits resistance to acids except oxidizing acids, but it has low resistance to bases. (Isran, 2018).

3. MATERIALS AND METHOD

3.1. Aramid Fiber

Aramid fibers are synthetic fibers known for their good heat resistance and strength. They possess excellent dampening qualities, are resistant to both acids and alkalis and are not easily combustible. Aramid is lighter yet stronger than steel. Aramid originated from the evolution of research on nylon and polyester materials. Nomex was developed in the early 1960s. Nomex is typically used in protective clothing, insulation, and as an asbestos substitute. Further research with meta-aramids led to the fibers we now recognize as aramid. Aramid and Twaron are para-aramids. Aramid was developed as a trademark by DuPont and became commercially available in 1973. (Tanner, Fitzgerald, & Phillips, 1989).

Figure 1. Aramid Fiber

Kevlar fiber material combines advanced technology by balancing strength with lightweight, enabling aramid fibers to enhance the performance of various industrial and military products. A single layer of aramid is less than 1 mm thick. There are three types of Aramids used in composite materials. Aramid 29 possesses strength like glass fiber but with a lighter weight. Aramid 49 and Aramid 149 can be utilized to reduce weight and exhibit good impact resistance.

3.2 Metode Glass Press

Glass Press is a specimen fabrication method in which the layer of resin and aramid is flattened between two layers of glass. Bubbles and excess resin will exit from the sides between the two glass layers. With this method, the resulting mold will be even and of high quality, representing a refinement of the hand lay-up process by incorporating a press formation concept to eliminate trapped air and excess resin, thereby reducing voids during the lamination process. The Glass Press method is an effective and cost-efficient technique that utilizes glass to achieve a fiber-to-resin ratio by optimizing strength aspects.

Figure 2. Metode Glass press

3.3 Additive Titanium Dioxide (TiO2)

Titanium dioxide is a simple titanium oxide extracted from natural minerals, namely ilmenite, rutile, and anatase. When purified from its natural mineral form, titanium dioxide is a white powder. This compound is primarily used as a pigment in paints and is also a common ingredient in inks, sunscreens, and food colorings. Titanium dioxide was first produced on a large scale as a pigment in 1916. The most common mineral source is ilmenite. Mineral sand rutile can also be processed to produce a pure form of this compound. The most used manufacturing method is the chloride process, which is used to separate titanium from its core.

$$TiO_2 + C \rightarrow Ti + CO_2$$

$$Ti + 2Cl_2 \rightarrow TiCl_4$$

$$TiCl_4 + O_2 \rightarrow TiO_2 + 2Cl_2$$

The sulfate process is also employed by several processing plants to produce pigment in crystalline form. The same process can also extract compounds and yield the anatase form of titanium dioxide. Anatase is a metastable mineral form of TiO2, commonly used in paper to enhance whiteness. TiO2 additive is a material form that receives special attention from researchers due to its particle size. The particle size of a material is an important factor influencing the effectiveness of its performance, especially for particles sized less than 100 nm. Furthermore, the TiO2 additive possesses several properties, including being an antibacterial agent that can strengthen microstructure, mechanical attributes, and operational treatment characteristics in a composite specimen. (UTOMO, 2021).

3.4 Sandwich Material.

The Sandwich material is a composite combination consisting of two or more skins or layers, with a core positioned between these skins. Sandwich materials are created to achieve a lightweight structure with high strength. The selection of materials for sandwich composites requires them to be lightweight, heat-resistant, and resistant to corrosion. By using a lightweight core material, a composite with strong, lightweight, and rigid properties can be produced. (UTOMO, 2021).

3.5. Body Armor

Body Armor, also known as bulletproof vests, is a protective layer or garment worn by personnel to prevent penetration from bullets. These vests are used to safeguard the chest, abdomen, and back. Vital human organs are situated between the back and chest, such as the heart, liver, lungs, digestive organs, and kidneys. Damage to these organs can lead to severe and even fatal consequences, including loss of life. Bulletproof vests are typically employed in the military domain.

During the Middle Ages, Japan created bulletproof vests made from a base of silk material. In the 1960s, the National Institute of Justice developed bulletproof vests using aramid fiber materials. The Army's Edgewood Arsenal (1973) also developed bulletproof vests with layered aramid fibers, totaling seven layers. Research conducted indicated that the highest energy absorbed and retained by bulletproof vests made of aramid was 27 J without any additional inserts. (UTOMO, 2021).

4. RESULTS AND TESTING

4.1. Brinell Test

The Brinell Test is a commonly used hardness testing method to measure the hardness value of a material by assessing the depth of an indentation formed by a spherical indenter. In the Brinell test, a hardened steel ball with a specific diameter, usually 10 millimeters, is pressed onto the surface of the test material with a known load. This load is usually applied for a certain period to create a sufficient indentation. After the load is removed, the diameter of the formed indentation is measured using an optical microscope.

The Brinell hardness value (HB) is then calculated by dividing the applied load by the surface area of the circular indentation. This value indicates the material's resistance to indentation and is typically expressed in pressure units, such as megapascals (MPa) or kilograms per square millimeter (kg/mm²).

This test is like the Rockwell hardness test. Hardness testing is conducted by creating an indentation on the surface of the test object using a hard steel ball that is pressed with a specific load. The load is applied for a certain period, usually 30 seconds, and the diameter of the indentation is measured under a microscope after the load is removed. The surface of the indentation should be relatively smooth, even, and free from dust or residue.

The results of Brinell specimen testing for body armor with varying layers of 14, 16, 18, and 20 layers are as follows: In specimens with 14 layers, it yielded an average of 253.6 HB for Brinell testing and an average of 98.5 HA for durometer testing. For specimens with 16 layers, It produced an average of 260 HB for Brinell testing and an average of 99 HA for durometer testing in specimens with 16 layers. For specimens with 18 layers, it resulted in an average of 277 HB for Brinell testing and an average of 99 HA for durometer testing. In specimens with 20 layers, the average was 278 HB for Brinell testing and 99 HA for durometer testing. From the Brinell test results, there is a tendency that as the number of layers increases, the Brinell hardness test results also increase. On the other hand, the durometer test results show a consistent tendency with values averaging around 99 HA.

4.2 Bending Test

Bending testing, also known as flexural testing, is a systematic procedure employed to visually assess a material's behavior when subjected to external forces that induce bending. This method involves the application of controlled pressure on the material to gather crucial data concerning its ability to withstand bending forces and stresses. In the context of this specific testing procedure, a cutting-edge Universal Tester, bearing the reputable QUALITEST brand, is employed. This advanced testing equipment is situated within the premises of the esteemed Chemical and Material Research Center, an integral part of the Naval Research and Development Office in Surabaya. The utilization of this state-of-the-art Universal Tester ensures precise and accurate measurements of bending strength, contributing to the comprehensive evaluation of the material's mechanical properties.

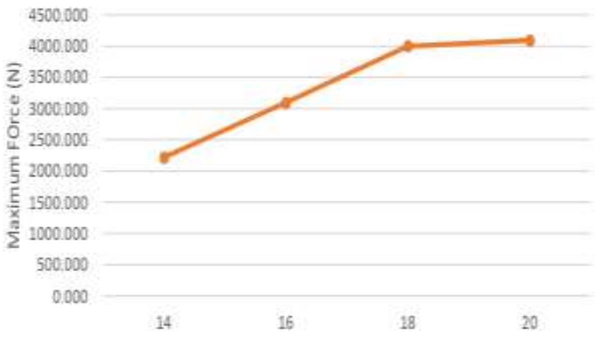

Figure 3. The Effect of Specimen Layers on Maximum Force

The results of bending test on body armor specimens with varying layers of 14, 16, 18, and 20 are presented. In specimens with 14 layers, it resulted in a maximum force of 2218.75 N and a maximum stress of 109.711 N/mm². For specimens with 16 layers, the maximum force recorded was 3093.75 N and the maximum stress was 116.054 N/mm². As for specimens with 18 layers It produced a maximum force of 4000 N and a maximum stress of 121.001 N/mm². In specimens with 20 layers, it yielded a maximum force of 4093.75 N and a maximum stress of 132.128 N/mm².

4.3 Ballistic Impact Test

This testing was conducted on 4 specimens of aramid fiber-reinforced composites with varying layer counts, carried out at the Naval Research and Development Center Laboratory, Madura, East Java. The shooting tests were performed using a special tool, the Gun Barrel, with MU1-TJ Luger/Parabellum caliber 9 x 19 mm bullets equipped with a Doppler System for bullet velocity measurement. Observation of the composite specimens after being subjected to 9 x 19 mm caliber projectile impacts was conducted on both the front and rear surfaces of the specimens. Several parameters were considered during specimen observation, such as the distance between impact points of the projectile on the specimen, which adhered to the stipulations of the National Institute of Justice (NIJ) standard 01.01.06, ensuring it did not exceed 2 inches. The specimens were not allowed to perforate, and the depth of deformation on the Back Face Signature (BFS) of each specimen did not exceed 44 mm.

Table 1. *Body Armor* Specimen Test Results with the First *Ballistic Impact* Test

No	Number of Layers	Shot Distance (meters)	Depth of Translucency (mm)	Information
1	14	5	+44	Bullet Translucen
		10	+44	
		15	+44	
		20	+44	
		25	+44	
2	16	5	+44	Bullet Translucen
		10	+44	
		15	+44	
		20	+44	
		25	+44	
3	18	5	+44	Bullet Translucen
		10	+44	
		15	+44	
		20	+44	
		25	+44	
4	20	5	+44	Bullet Translucen
		10	+44	
		15	+44	

Table 2. *Body Armor* Specimen Test Results with the Second *Ballistic Impact Test*

No	Number of Layers	Shot Distance (meters)	Depth of Translucency (mm)	Information
1	14	5	+44	Bullet Translucen
		10	+44	
		15	+44	
		20	+44	
		25	+44	
2	16	5	+44	Bullet Translucen
		10	+44	
		15	+44	
		20	+44	
		25	+44	
3	18	5	+44	Bullet Translucen
		10	+44	
		15	+44	
		20	+44	
		25	+44	
4	20	5	42,12	Bullet Translucen
		10	28,22	
		15	23,27	
		20	18,72	
		25	-	Bullet not Translucent

Table 3. Ballistic Impact Test

Protection Level	Test Weapon	Bullet Mass	Distanceto Soft or Hard armor (m)	Maximum BFS (mm)	Velocity Conditioned Testing of *Body Armor* (m/s)	Velocity forNew and Unworn *Body Armor* (m/s)
IIA	mm FMJRN	8.0 g (124 gr)	5m ± 1	44	355	373
	.40S&WFMJ	11.7 g(180 gr)	5m ± 1	44	325	352
II	mm FMJRN	8.0 g (124 gr)	5m ± 1	44	379	398
	.357 Magnum	10.2 g(158 gr)	5m ± 1	44	408	436
IIIA	.357 SIGFMJ FN	8.1 g (125 gr)	5m ± 1	44	430	448
	.44 MagnumSJHP	15.6 g(240 gr)	5m ± 1	44	408	436
III (3)	7.62 mmNATO FMJ	9.6 g(147 gr)	15m ± 1	44	847	847
IV (4)	0 CaliberM2 AP	10.8 g (166 gr)	15m ± 1	44	878	878
Special	Special threats need to be specified by the manufacturer					

Ballistic impact is a property that arises when the material is subjected to ballistic load. Ballistic studies the motion of bullets (projectiles) fired until they hit the target and the effects of the target hit by the motion of the bullet. Balistic impact causes high local deformation and damage It travels at approximately the same speed as the ship, whereas at slow speeds, several waves exist along the length of the ship because the wavelength is smaller than the length of the ship. And as the ship accelerates, the transverse wavelength increases. When the transverse wavelength approaches the length of the vessel, the wave-making resistance increases very quickly.

Figure 4. The result of the Ballistic Impact Test

4.3.1 Charpy Impact Testing Method

This testing was carried out on 4 specimens for each respective variable, measured according to the American Society for Testing and Materials (ASTM) standard for specimen measurements (ASTM E23). The standard specifies a specimen length of 55 mm, width of 10 mm, and height corresponding to material thickness with a keyhole notch. The notch angle size for the specimens was 600 with a depth of 2 mm. Generally, this method is employed due to its higher accuracy in results, easier comprehension and execution, uniform stress distribution across the cross-section, and shorter required testing time. Below are photos of the composite specimen testing results before and after the tests, as shown in Figure 5:

Figure 5. Specimen After Charpy Impact Testing

4. CONCLUSION

Based on the analysis of the results of the Ballistic Impact Test, Charpy Method Impact Test, Brinell Hardness Test, and Bending Test, it can be concluded as follows:

a. The effect of aramid fiber arrangement layer with the addition of Nano Titanium Dioxide additives and epoxy resin on the physical properties of composites, in body armor specimens can increase the value of density, water absorption, tensile strength, and hardness of the specimen.

1. b. Impact resistance on aramid fiber specimens with variable aramid fiber arrangement layers in the Ballistic Test test can be made to see the resistance to shock waves on each specimen that has been made. The results obtained resulted in specimens with several layers of 14, 16, and 18 experiencing failures characterized by specimens unable to withstand bullets so that bullets could penetrate specimens until they were hollow. Meanwhile, specimens with 20 layers managed not to penetrate. This shows that the more layers, the better the resistance to shock wave resistance, which in this case is a specimen with a total of 20 layers. The specimens in this study have met the National Institute of Justice (NIJ) Standard 01.01.06

2. c. The durability of material properties in aramid fiber specimens with variable layers of aramid fiber arrangement in the Charpy Method Impact test shows that the more the number of layers, the higher the impact price produced. So, it can be concluded that body armor specimens that have a layer count of 20 generate a price

d. The highest impact is 0.259 Joule/ mm2. While the Bending Test shows that the more the number of layers, the higher the maximum force and maximum stress price. So, it can be concluded that body armor specimens that have a number of layers of 20 produce the highest maximum force and maximum stress prices, namely maximum force of 4093.75 N and maximum stress of 132.128 N / mm2. The specimens in this study have met the standards of American Standard Testing and Materials (ASTM E23).

e. Can design aramid fiber that is effective and efficient and resistant to ammunition fire which is able to carry out tests by showing that the body armor specimen with 20 layers is stronger with a cross-sectional area of 35.7 mm2, cos β of 560, impact price of 0.259 Joule / mm2, 278 HB for Brinell test, 99 HA for durometer test, the maximum force of 4093.75 N and maximum stress of 132.128 N / mm2.

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