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ENHANCING BALLISTIC IMPACT RESISTANCE OF ARAMID FIBRE COMPOSITE (KEVLAR) WITH NANO TITANIUM DIOXIDE (TIO_2 NP) ADDITIVE FOR ANTI-BULLET VEST APPLICATION

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ABSTRACT

Composite is a combination material consisting of two or more different components, with the aim of obtaining better physical and mechanical properties. One of the advantages of composite materials is their lightweight and anti-corrosion properties. Composite applications include materials for making aircraft and materials for making bullet-proof vests. Generally, the bullet-proof vest used by the TNI is made of 15 mm thick steel and has a total weight of 10 kg. In this study, the author will examine the application of aramid fibre (kevlar) as a composite material for bulletproof vests and will analyze the use of composites made using the Vacuum Bagging method which is a refinement process of the hand layup method with variations of Nano Titanium Dioxide (TiO2 NP). To determine the characteristics of Nano Titanium Dioxide (TiO2 NP), the authors used a Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS). Testing the results of the research, namely the shooting test using 9 mm calibre bullets at 5 m with a gun barrel to analyze the ballistic impact. The analytical parameter used is the National Institute of Justice (NIJ 0101.06) level II. In addition to the firing test, impact testing of the specimen will also be carried out using the Charpy method, the Brinell and Rockwell hardness test and the Bending Test. The test specimens were made using the Japanese Industrial Standards (JIS-Z-2202) size standard. From the implementation of some of these tests, the ballistic impact test obtained the results that the TiO2 NP variable of 0%, 5%, and 10% did not meet the requirements for bulletproof vests because there was a penetration that exceeded the standard and bullet penetration, for specimens with a composition of 15% it had the best impact strength and bullet impenetrable. For the impact test results of the Charpy method, the highest impact value on the A15 specimen is 35 J/cm2, and then in the Rockwell hardness test with 4 points of emphasis, the highest average value on the A15 specimen is 35.70. For the Brinnel test, the highest HB value in the A15 specimen was 13.26. For the bending test, the highest strength on the A15 is 71.90 N/mm2. So, the A15 specimen meets the requirements to be used as an alternative material for bulletproof vests.

Keywords: *Composite, Aramid (kevlar), Bulletproof Vest, Ballistic Impact, Titanium Dioxide (TiO2 NP).*

1. INTRODUCTION

One of the defence and self-protection equipment used by Indonesian National Armed Forces (TNI) soldiers, especially Air Force Special Forces (Paskhas AU) and other personnel deployed in operational areas, is body armour. The body armour serves the main function of resisting penetration and reducing the impact power of projectiles. During collisions, the kinetic energy of the bullet is absorbed and distributed across the surface area of the protective plate of the vest, while the remaining energy is transmitted to the soldier's body. Typically, bulletproof vests are made from steel, weighing approximately 10 kg.

Based on the case study, the author examines alternative materials for manufacturing lightweight bulletproof vests that possess nearly the same strength as the previous material. The primary objective in selecting these composite materials is to ensure the effectiveness and comfort of personnel when used over an extended period. High-strength technical fibres are used as reinforcements in the composite for body armor with various variations. Types of technical fibres such as aramid fibre, carbon fibre, and fibreglass are intriguing for development in body protection manufacturing due to their superior properties compared to conventional materials, such as low density, flexibility, high rigidity, and sufficient impact resistance. Aramid fibre is a type of synthetic fibre that is heat-resistant and strong, making it suitable as a reinforcement for composite materials and widely used in military personnel body protection applications. Aramid fibre possesses distinctive characteristics of high strength and rigidity, albeit being relatively expensive, requiring specialized studies to determine the optimal number of fibre layers to achieve optimal ballistic impact properties.

The author utilizes one type of fibre, namely aramid, with an equal number of layers, which is 21 layers, with a variable composition of Nano Titanium Dioxide (TiO_2NP) particles as a filler or resin reinforcement, with the hope of obtaining better ballistic impact test results than the previous research (Ceng Yanen, 2016).

Polymer, specifically polyester, is widely used in composite applications as the binding phase for technical fibre due to its high bending strength, low shrinkage during consolidation, and extended consolidation time at room temperature, allowing for temperature variation during consolidation. On the other hand, for filler applications in ballistic composite, materials such as Aluminum Oxide and Silicon Carbide have been developed and demonstrated to improve the ballistic impact resistance of the composite with varying additions. In this research, the author uses Nano Titanium Dioxide (TiO_2 NP) particles, which have the potential to be used as fillers in body armor specimen production due to their anti-bacterial properties, ability to reinforce microstructure and mechanical properties, as well as their effectiveness during operational treatment of a composite specimen.

2. LITERATURE REVIEW

According to NIJ 0101.06 level II, where the Back Face Signature (BFS) is less than 44 mm and the bullet does not penetrate, it can be concluded that the bulletproof vest with a thickness of 10 mm, with the kinetic energy transmitted to the body, remains within the safe limit. (Ashari, 2017). Other research by the addition of epoxy in the composite improves the interface formed between the fibre and matrix. By using Scanning Electron Microscope (SEM) images, the average size of glass fibre is obtained to be 16.19 micrometres. (Andaru, 2017).

Various mechanisms that influence the ballistic performance of composites are mentioned, and it is stated that all parameters affecting ballistic penetration resistance, particularly the properties of the fibre material, fabric architecture, projectile geometry, impact velocity, frictional effects, and boundary conditions, are interconnected. (Dimeski, 2015).

Hybrid composite and Cocos Nucifera/CS/ epoxy composite panels demonstrate higher energy absorption capacity (30%) and ballistic limit (13%) compared to other composites. This is due to the unique chemical composition of Cocos Nucifera/CS, architecture, and mechanisms of shock wave mechanical energy dissipation. Therefore, this new environmentally friendly material will efficiently serve as an alternative in ballistic composites. (Naveen, 2018).

The mechanical properties of the composite experience a decrease in tensile strength but an increase in elongation and impact strength with the electropolymerization of carbon fibres with aniline or MMA. The tensile strength value for SK/epoxy bulletproof vests exceeds that of Kevlar/epoxy/ Al2O3 powder bulletproof vests. Thus, it can be applied to NIJ standard type II and IIA. (Ramadhanu, 2018).

3. MATERIALS AND METHOD

3.1. Composite

Composite is an engineered material composed of two or more materials combined on a macro scale in different forms and compositions that are insoluble in each other with distinct phases. Macro scale means that the original components can still be seen after mixing (Schwartz, 1984).

The purpose of creating composites is to obtain a new material with improved mechanical properties compared to the original materials. Composites generally consist of two parts or phases, namely the matrix and reinforcement. The first phase is the matrix, which acts as a binder, such as metals, ceramics, and polymers. Meanwhile, the second phase is the reinforcement, which strengthens the composite material, such as fibres and particles. Composite is a non-metal material that also exhibits fatigue life like metal materials. Material damage occurs due to repetitive loading. In metal materials, fractures may occur, but in non-metal materials like composites made from aramid and carbon fibres, the damage is limited to the layers, without complete fracture. This is due to the inherent toughness of the composite material.

Composite has a good strength-to-density ratio. This advantage, when used as a material for bulletproof vests, can lead to more efficient mobility due to its lighter weight compared to metals. The strength of this composite material is up to 3 to 5 times better than steel.

3.2. Matrix

Matrix is the dominant component compared to reinforcement in a composite material. The matrix functions as a binder, holding, and stress transfer medium for the composite material. On the other hand, the filler serves as the primary stress recipient dispersed within the matrix. The essential requirement for the matrix in composites is to be able to transmit loads, allowing the fibres to adhere to the matrix and maintain compatibility between the fibres and the matrix. Matrix materials in composites can be metals, ceramics, or polymers. Generally, matrices are selected for their high heat resistance characteristics. (K Diharjo, 2000).

3.3. Resin Polyester (UPR).

Unsaturated Polyester Resin (UPR), also known as fibreglass resin, has been widely popular in the shipbuilding industry since the 1930s before the emergence of epoxy. That's why this resin is known as ship resin. It comes in various colours such as red, white, yellowish, and green. Through a chemical reaction, where the resin and hardener or the resin with its catalyst are mixed in one place, the hardening process occurs. If too much catalyst is added to the mixture, it will generate heat during the hardening process. Polyester resin will appear slightly transparent when applied in thin layers without any additives. This resin is specifically designed with a sticky surface finish in open air to strengthen subsequent bonding. (Sara Kadolph and Anna Langford. 8th Edition, 1998).

3.4. Fibre

Fibre is a material consisting of elongated pieces that form a continuous network. An example in daily life is the fibres present in fabrics. This material is essential in biology for animals and plants as it acts as a binder in their bodies. Humans use fibres for various purposes such as making ropes, fabrics, or paper. Fibres can be classified into two types: natural fibres and synthetic fibres (man-made fibres). Synthetic fibres can be produced inexpensively in large quantities. However, natural fibres have various advantages, especially in terms of comfort. (Chawla, 1987).

3.5. Aramid Fibre

Aramid fibre is an acronym for aromatic polyamide. It is a synthetic fibre that is heat-resistant and strong, with excellent damping properties, and is resistant to acids and bases, making it non-flammable. Aramid is lightweight but stronger than steel. Aramid has evolved from research dating back to nylon and polyester. Nomex was developed in the early 1960s and due to its properties, it is used in protective clothing, insulation, and as a substitute for asbestos. Further research with meta-aramid led to the fibre we now know as Kevlar. Kevlar and Twaron are para-aramids. Kevlar was developed and trademarked by DuPont and became commercially available in 1973. The shape of aramid fibre is shown in figure 1 below. (Tanner, Fitzgerald, & Phillips, 1989).

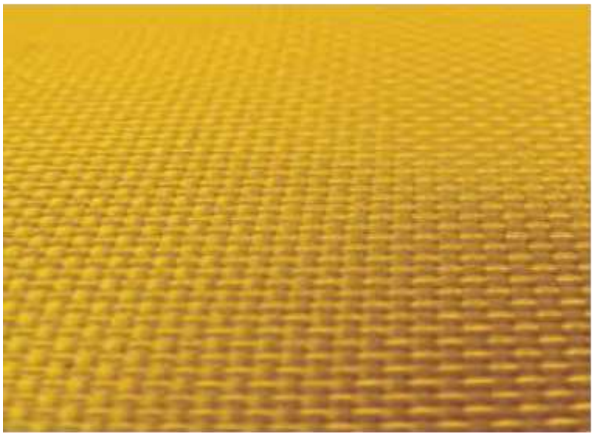


Figure 1. Aramid Fibre

Advanced technology that combines strength with relatively lightweight to enhance the performance of various industrial and military products. One layer of aramid is less than 1 mm thick. Below is the chemical structure of aramid fibre (figure 2).

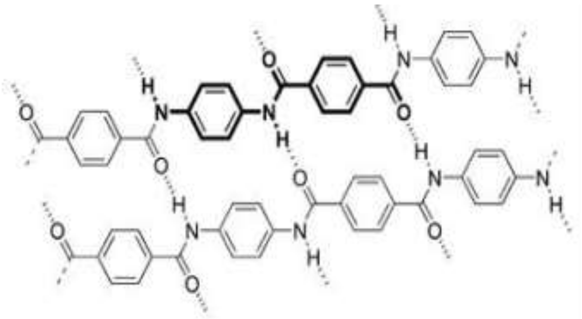


Figure 2. Chemical structure of aramid fibre

3.6. Vacuum Bagging

Vacuum bagging is an enhancement of the hand lay-up process that utilizes the concept of creating a vacuum to remove trapped air and excess resin, eliminating voids from the lamination. This cost-effective and efficient technique uses vacuum pressure to optimize the fibre-to-resin ratio in terms of strength (M. Lakshmi Aparna, 2016).

In vacuum bagging, atmospheric pressure is used as a clamp to press the layers of lamination together with equal and uniform pressure. The lamination is enclosed in an airtight bag. During the vacuum process, it is ensured that no air escapes from the entire sealed layers, especially at the junction between the pneumatic pipe and the port connector, and other areas. To ensure no air leaks, a noisy detector tool is used by operators to check every side of the lamination and the connections. If there are still air leaks, the vacuum process will not be as effective as desired. When the lamination is sealed, the air pressure inside and outside the mold is equal to atmospheric pressure, around 14.7 Psi. Then, the vacuum pump is turned on to create a negative pressure of (-98 KPa). As shown in Figure 3. below.

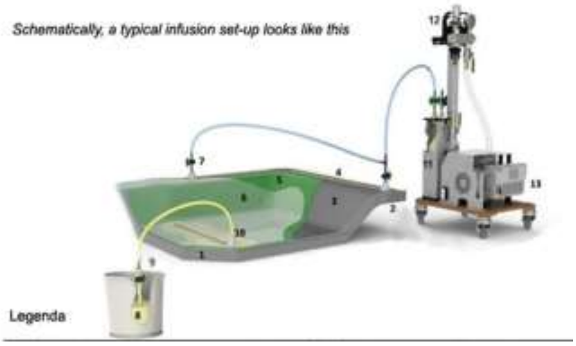


Figure 3. Skema Vacuum Bagging

4. DISCUSSION AND RESULTS

4.1. Data Analysis

The implementation of data analysis on composite specimens in this study was carried out after all specimens were ready, and then samples were taken from several of these variables according to Japanese Industrial Standards (JIS-Z-2202) size parameters, to carry out impact testing using the Charpy method, Brinell hardness test, Rockwell hardness and bending test. In addition, to determine the characterization of the TiO2 NP additive, Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS) were used to determine the surface texture and composition of the chemical elements, respectively. In Figure 4. the SEM image shows that the TiO2 NP additive in micro has a rough, layered, and non-porous surface texture.

Figure 4. SEM image of TiO_2 NP

Furthermore, in Figure 5. a graph of the weight composition of each constituent of the Titanium Dioxide (TiO2 NP) additive is shown. The largest elements are Titanium (Ti) and Oxygen (O2) with percentages of 47.17% and 44.56%, respectively. Titanium Dioxide (TiO2 NP) additive also contains other elements such as Nitrogen (N2) 5.95%, Aluminum (Al) 1.60%, and Carbon (C) 0.72%. Based on this data, the effective powder to be used as a composite filler is the Titanium Dioxide (TiO2 NP) additive.

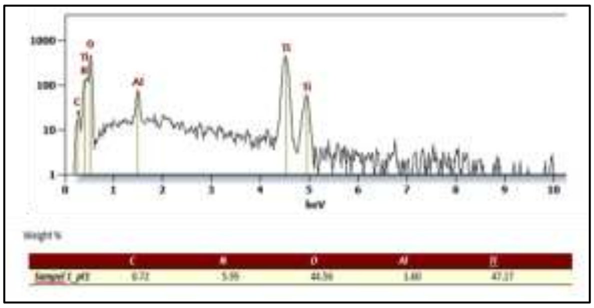


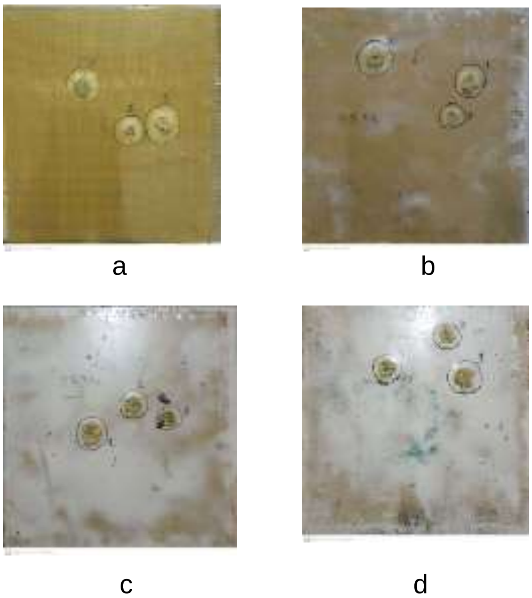
Figure 5. Testing EDS Aditif Titanium Dioksida

4.2. Material Testing

The specimen testing was conducted using several methods, namely:

a. Ballistic Impact Test.

This test was performed on 4 composite specimens reinforced with aramid fibers and with varying Titanium Dioxide (TiO2 NP) additives at the Naval Weapons and Ordnance Laboratory of the Indonesian Navy in Madura, East Java. The shooting test was carried out using a special tool called the Gun Barrel, with MU1-TJ Luger/Parabellum 9 x 19 mm caliber bullets, equipped with a Doppler System for bullet velocity measurement. Post-shooting observations of the composite specimens were made on the front and back surfaces on a macroscopic scale. Several parameters were observed, such as the distance between projectile impact points on the specimens, which complied with the National Institute of Justice (NIJ) 01.01.06 standard, not exceeding 2 inches. The specimens should not be penetrated, and the depth of deformation in the BFS (Back Face Signature) of each specimen should not exceed 44 mm. Below are the macroscopic photos of the four composite specimens after the ballistic impact test as shown in the figure.



a b

c d

Figure 6a. A0 (Aramid fibre + resin) composite, **6b.** A5 (Aramid fibre + resin + 5% TiO2NP) composite. **6c**. A10 (Aramid fibre + resin + 10% TiO2NP) composite. **6d**. A15 (Aramid fibre + resin + 15% TiO2NP) composite

Meanwhile, the complete test results can be seen in the following table.

Table 1. Overall Results of Ballistic Impact Testing

Spes	**%** ***Filler*** **TiO_2NP**	**Deep Deformation BFS (mm)**	**standart NIJ level II**
A0	0	14	Not Pass
A5	5	14,5	Not Pass
A10	10	15	Not Pass
A15	15	15	Pass

Based on the results of the ballistic impact test in Table 1, in general, composite specimen A0 (without the addition of TiO2 NP additive), composite specimen A5 (with 5% TiO2 NP additive), and composite specimen A10 (with 10% TiO2 NP additive) did not meet the requirements of the materials for bulletproof vests according to the NIJ 0101.06 Level II standard, as there were still projectiles penetrating the back face signature (BFS), which could be fatal to the human body. On the front side (the direction the projectile came from), all specimens showed delamination of the fibre layers around the projectile impact area. However, composite specimen A15 (with 15% TiO2 NP additive) met the requirements because none of the projectiles penetrated the specimen or caused back-face signature (BFS) issues.

For specimens capable of withstanding the projectile velocity, such as specimen A15, there were efforts to contain the projectile velocity, evident from matrix cracks and reinforcement fibre delamination. This indicates a well-integrated matrix-fibre interface and the effective role of TiO2 NP additive in strengthening the matrix and effectively filling void spaces in the composite.

On the other hand, for specimens A0, A5, and A10, although one projectile was able to withstand the projectile velocity, subsequent shots penetrated the layers. The conclusion from the above test is that the addition of TiO2 NP additive variables has an impact on ballistic impact, where percentages from 0% to 10% were not able to meet the requirements of bulletproof vest materials. It was only at the 15% variable that the requirements were met.

b. Charpy Impact Test Method.

In this test, 4 specimens from each variable were tested according to the standard measurements of Japanese Industrial Standards (JIS-Z-2202), which specify the specimen dimensions as 55 mm in length, 10 mm in width, and 10 mm in height. The notched specimen angle is set at 45 degrees with a depth of 2 mm. Generally, this method is used because it provides more accurate results, is easier to understand and perform, produces uniform stress along the cross-section, and requires less time. Below are the photos of the composite specimens after undergoing the impact test as shown in figure 7.

a b

c d

Figure 7a. A0 (Aramid fibre + resin) composite, **7b**. A5 (Aramid fibre + resin + 5% TiO2NP) composite. **7c.** A10 (Aramid fibre + resin + 10% TiO2NP) composite. **7d.** A15 (Aramid fibre + resin + 15% TiO2NP) composite

From this study, it was found that the energy required to fracture the specimens ranged from approximately 33 J to 70 J. The initial pendulum angle was set at 1500. The final pendulum angle after fracturing the specimens ranged from 860 to 1180. Based on table 16, the graph below shows the absorbed energy and impact value for each specimen:

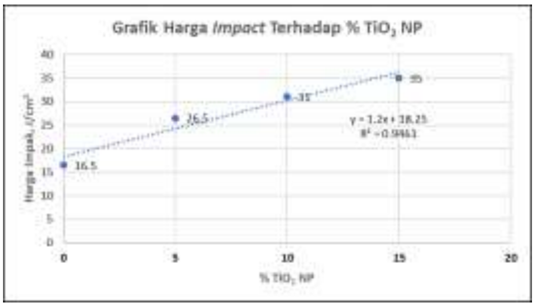


Figure 8. Graph *Impact Value based* % TiO$_2$ NP

c. Rockwell Hardness Test.

In this test, 4 specimens from each variable were tested according to the standard measurements of Japanese Industrial Standards (JIS-Z-2202), which specify the specimen dimensions as 2 cm in length, 2 cm in width, and 2 cm in height. The Rockwell test was conducted at the Material Engineering Laboratory, AAU, Yogyakarta, using a Mitutoyo ATK-F1000 hardness tester. The Rockwell test produces smaller and finer indentations. Below is Figure 8 with the results of the Rockwell hardness test.

a b

c d

Figure **9a**. A0 (Aramid fibre + resin) composite, **9b**. A5 (Aramid fibre + resin + 5% TiO2NP) composite. **9c.** A10 (Aramid fibre + resin + 10% TiO2NP) composite. **9d.** A15 (Aramid fibre + resin + 15% TiO2NP) composite.

Then, the hardness values of the aramid fibre (Kevlar) with different TiO2 NP additive levels tend to increase as the additive percentage increases. Based on Table 17, the graph below shows the Rockwell hardness (HRF) values for each specimen:

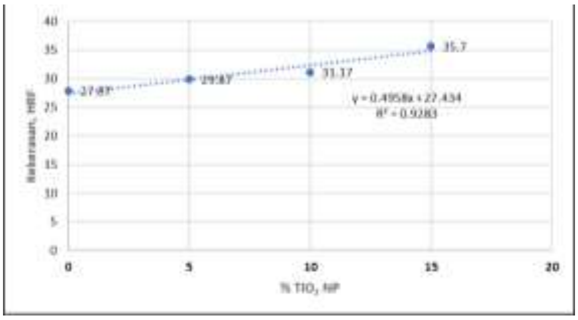


Figure 10. Hardness test based % TiO$_2$NP.

d. Bending Test.

The bending test is a visual material testing process where the material is subjected to compression to obtain data on the bending strength of the tested material. In this test, a Universal Testing Machine, QUALITEST brand, located at the Material Engineering Laboratory, AAU, Yogyakarta, was used. Below is Table 8 with the results of the bending test.

The bending test results were conducted at the Material Engineering Laboratory of AAU, Yogyakarta. The tested specimens had dimensions of 10 cm in length, 2 cm in width, and 2 cm in height. The Bending Testing Machines brand Qualitest was used for the testing. From the test results of the specimens, quantitative data were obtained as shown in Table 2.

Table 2. Data Pengujian Lengkung (Bending)

Spesimen	Beban Maksimal (N)	Defleksi (mm)	***Bending Strength*** **(N/mm^2)**
TiO$_2$ NP 0%	3303,9	2,70	60,52
TiO$_2$ NP 5%	3491,4	2,87	63,61
TiO$_2$ NP 10%	3669,5	6,20	67,67
TiO$_2$ NP 15%	4148,1	5,51	71,90

From the bending test results and based on the table above, with one-time pressing, the composite data using TiO2 NP with 0% variation shows a maximum load value of 3303.9 N, a deflection length of 2.70 mm, and a bending strength of 60.52 N/mm². Meanwhile, the 5% variation exhibits a maximum load value of 3491.4 N, a deflection length of 2.87 mm, and a stress value of 63.61 N/mm². The 10% variation shows a maximum load value of 3669.5 N, a deflection length of 6.20 mm, and a stress value of 67.67 N/mm². Lastly, the 15% variation displays a maximum load value of 4148.1 N, a deflection length of 5.51 mm, and a stress value of 71.90 N/mm². The conclusion from the maximum load values of aramid fibre (kevlar) composite with TiO2 NP additive variations tends to increase with the increase in the variable. Based on Table 2, the graph of bending test values for each specimen can be shown as follows:

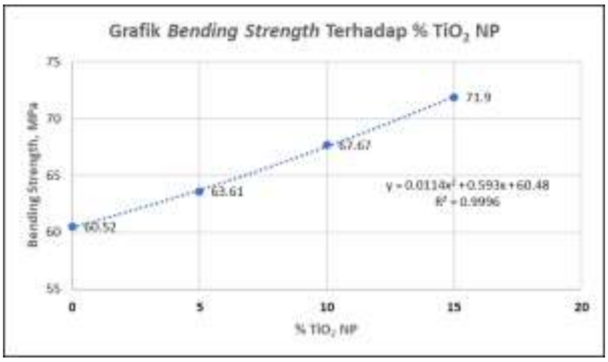


Figure 9. Graphic *Bending Strength* based % TiO$_2$ NP

From the graph above, it is shown that the lowest maximum stress value is obtained in the specimen with 0% TiO2 NP additive, which is 67.67 N/mm2, while the highest maximum stress is obtained in the specimen with 15% TiO2 NP additive, which is 71.90 N/mm2. The maximum stress values of the aramid fibre (kevlar) composite with different TiO2 NP additive levels tend to increase as the additive percentage increases.

5. CONCLUSION

Based on the result and discussions, we can take some conclusions are:

a. Based on the results of the conducted testing on composite specimens with varying TiO2 NP additive percentages of 0%, 5%, 10%, and 15%, it can be concluded that the effective composition for the TiO2 NP additive in specimen production is specimen A15 (with a 15% TiO2 NP content). Therefore, this material is highly suitable for the production of bulletproof vest materials.

b. Composite specimens reinforced with aramid fibers that meet the body armor standard NIJ 0101.06 level II and have the best ballistic impact resistance are the specimens with the addition of 15% TiO2 NP additive by weight of resin.

c. The more TiO2 NP additive variables, the greater the Impact Value (HI) obtained. This is undoubtedly due to the stronger bonding of the filler to the resin and fiber, and also affects the angle after impact (β) to be larger. Specimen A15 has the highest HI value compared to other percentages.

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