Vol. 8, No.2, Juli 2025, Halaman 395-404 | ISSN 2622-7398
DOI:https://doi.org/10.30596/rmme.v8i2.22652 | http://jurnal.umsu.ac.id/index.php/RMME
Jurnal Rekayasa Material, Manufaktur dan Energi

Development Composite Metal-Ceramic Hybrids and Polymer Foam Composites Reinforced TKKS Fiber with Variations Al2O3 Concentration for Enhancement Mobility and Protection Armored Vehicle

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ABSTRACT
Armored vehicles require materials that can provide high protection from ballistic and explosive threats, and have a light weight to increase mobility. This study aims to develop metal-ceramic hybrid composites and polymer foam composites reinforced with OPEFB (Oil Palm Empty Fruit Bunches) fibers with varying concentrations of Al2O3 (Aluminum Oxide). This combination was tested to assess mechanical strength, ballistic resistance, and energy absorption capabilities from impacts and shock waves. The results showed that the composite using a 10% Al2O3 concentration variation provided the best balance between strength and light weight. The use of these two types of composites is expected to increase the mobility and protection of armored vehicles.

***Keywords** : Metal-ceramic hybrid composites, polymer foams, OPEFB fibers , Al2O3, armored vehicles, ballistic protection.*

INTRODUCTION

Armored vehicles, whether used for military or civil security purposes, face a major challenge in maintaining a balance between optimal protection and mobility. Good protection requires materials that are able to withstand ballistic and explosive attacks, but these materials are usually heavy. The heavy weight of armored vehicles can reduce speed, increase fuel consumption, and reduce operational efficiency. Conversely, if material protection is reduced to reduce weight, the risk of damage or harm to personnel inside increases (Barrowes et al. 2019) . Therefore, research into the development of composite materials that have high strength, resistance to attacks, but remain lightweight, is very important.

One type of material that is promising in this regard is a metal-ceramic hybrid composite. This material combines the advantages of ceramics in resisting projectile penetration with the ability of metal to absorb energy from impact. Ceramics are able to withstand and inhibit projectile penetration well, while metals provide flexible structural support so that energy from impact can be absorbed and dampened, reducing the possibility of damage to the inner layer of the vehicle (Fabris et al. 2017). In addition, polymer foam composites reinforced with natural fibers, such as Empty Oil Palm Bunches (EFB), are also considered an attractive alternative because they have a light weight and fairly good mechanical properties. In this study, the addition of Al_2O_3 (aluminum oxide) to the polymer foam composite aims to increase the hardness and resistance of the composite to high temperatures and impacts. With the additional properties of Al_2O_3, the composite is expected to be more resistant to extreme conditions often faced by armored vehicles (Aksara, Akademia, dan Akademia 2024).

The purpose of this research is to develop optimal composite materials for armored vehicles. By utilizing a combination of metal, ceramic, polymer, and Al_2O_3 reinforcement materials, it is expected to create materials that can improve the ballistic protection of vehicles without significantly increasing weight, so that vehicle mobility is maintained or even improved.

RESEARCH METHODS

This research consists of two main parts, namely the development and characterization of metal-ceramic hybrid composites and polymer foam composites reinforced with TKKS fibers with the addition of Al2O3. The research stages include:

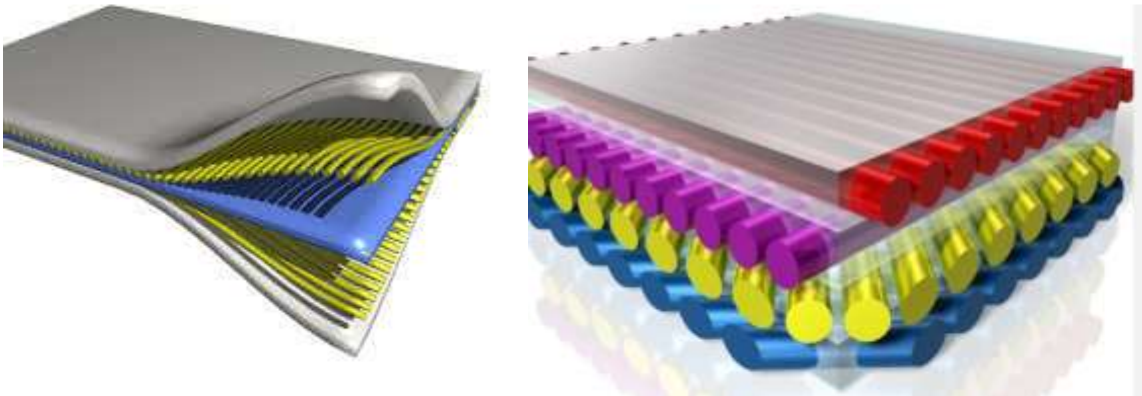

Figure 1. Composite materials (Barrowes et al. 2019)

Metal-Ceramic Hybrid Composites
Metal-ceramic hybrid composites are composite materials that combine metal as the main matrix and ceramic as a reinforcement to produce a material that has the advantages of both materials. This composite aims to obtain optimal mechanical properties, such as high strength, wear resistance, and remains lightweight. The following is an explanation of the material, manufacturing method, composition, and purpose of this composite(Gomez 2012):
Materials Used:

- **Aluminum (Al) metal** : Aluminum is used as material base or matrix composite . Selected Because :
  - **Lightweight** : Provides advantages in terms of mobility and energy efficiency, especially for applications in vehicles and aircraft.
  - **Corrosion Resistance** : Increases the material's resistance to corrosive environments, thereby extending its service life.
  - **Conductivity Good Thermal and Electrical Properties** : Making aluminum very suitable For applications that require rapid heat transfer .
- **Aluminum Oxide Ceramics (Al_2O_3)** : Functioning as a filler or amplifier . Al_2O_3 was chosen because:
  - **High Hardness** : Provides resistance to scratches and wear, which is critical in applications with severe working conditions.
  - **High Melting Point** : Add resilience heat , making the material stable in temperature tall .
  - **Fragile** : Weakness experience ceramics This dealt with with combine it to in matrix aluminum metal , producing the optimal combination between strength and flexibility composite (Williams, Ary Subagia, dan Sri Komaladewi 2019).

Method of manufacture :

Pressure-Assisted Sintering : Is a technique manufacturing where temperature and pressure used simultaneously For unite particle metal and ceramics . This process increase diffusion between particle so that composite become more solid and strong . Advantages method This is his ability For produce material with porosity low and integrity high structural , so that suitable For composite metal-ceramic with characteristic optimal mechanics .

On composite based on aluminum with reinforcement ceramics , **proportions content Al_2O_3 is 30% of the total mass composite** chosen to achieve optimal balance between strength , endurance wear , and material flexibility . Al_2O_3 as a ceramic component plays a major role in increasing the mechanical strength of the composite and its resistance to wear. With a composition of 30%, Al_2O_3 provides significant improvements in these properties, making the composite more durable and

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suitable for heavy applications involving high friction or pressure. However, adding ceramics in too high an amount, for example more than 30%, can make the material too hard and brittle, reducing its flexibility and ability to withstand deformation without cracking. With a proportion of 30%, the composite maintains its flexibility, so it can more effectively withstand various external forces without easily breaking or cracking. This ratio is considered ideal for maintaining the desired mechanical characteristics without sacrificing durability or performance in structural applications that require high strength and long-term durability (MY and F. Lubis 2016).

Purpose of Using Composites:

The purpose of using composites that combine aluminum (Al) and aluminum oxide (Al_2O_3) is to create materials with superior properties that are more suitable for applications in various industries. First, **to increase mechanical strength and wear resistance** , the combination of aluminum with Al_2O_3 produces a material that is stronger and more resistant to wear compared to pure aluminum. This makes the composite more durable when used in applications that require resistance to heavy loads or friction, such as in automotive components or industrial tools. Second, **it has adequate thermal conductivity** (Bale et al. 2020), where aluminum as a matrix maintains good thermal conductivity, which is very important for applications in engines or automotive components that require fast heat transfer to prevent overheating. Finally, **this composite is suitable for various applications** , such as in the automotive, aviation, and other mechanical industries, because it combines structural strength, wear resistance, and the ability to transfer heat efficiently, making it ideal for extreme operational conditions or high-temperature environments (Thoriq et al. 2022)

Polymer Foam Composite Reinforced with TKKS Fiber

Material Used: Polymer Foam (Polyurethane)

Polyurethane foam is a type of polymer material that has a flexible and lightweight structure, often used in various industrial and consumer applications due to its unique properties. This polyurethane is a popular choice for foam products due to the following characteristics:

- **Flexibility** : Polyurethane foam is highly elastic, allowing the material to return to its original shape after being subjected to stress or deformation. This flexibility makes it ideal for applications that require a material that can absorb impact and return to its original shape, such as in shock absorbers or cushions.
- **Durability** : Polyurethane has good resistance to wear and degradation, making it suitable for long-term use. This makes it a material that can withstand a variety of environmental conditions without losing performance.
- **Good Insulation Properties** : Polyurethane is also known for its ability to insulate heat and sound, making it ideal for use as an insulating material in the construction, automotive, and electronics industries. These insulating properties are very useful in maintaining room temperature or reducing noise.

However, polyurethane has a disadvantage in terms of structural strength. By nature, this material is not very strong and is prone to excessive deformation if used without additional reinforcement. In applications that require higher structural strength, such as in composite structures, polyurethane foam is often combined with other materials to increase its strength. Because of these properties, polyurethane foam is widely used in various applications including seats, shock absorbers, thermal insulation, and automotive products, where flexibility, durability, and insulation are key factors (Dian 2017).

TKKS (Empty Oil Palm Bunches) Fiber

Figure 2. TKKS cellulose fiber after the delugnification process (Thoriq et al. 2022)

Natural fibers taken from oil palm agricultural waste. OPEFB is chosen because of its lightweight, easy to obtain, and environmentally friendly properties (Barrowes et al. 2019). In addition, OPEFB fiber processing can improve mechanical properties such as tensile strength and resistance to damage. Al_2O_3 (aluminum oxide) is used as a filler in polymer-based composites to increase the strength, hardness, and thermal resistance of the material. With strong mechanical properties, Al_2O_3 strengthens the polymer, increases resistance to scratches and wear, and provides protection against high temperatures thanks to its excellent thermal resistance. In addition, Al_2O_3 also improves chemical stability and corrosion resistance, making it an ideal choice for applications in environments that demand structural strength and high temperature resistance .

Composite The addition of Al_2O_3 to polymer foam with concentration variations of 5%, 10%, and 15% aims to improve the mechanical and thermal properties of the foam, such as strength, hardness, and resistance to high temperatures. Although improvement concentration Al_2O_3 can repair properties said , higher concentration need optimized so as not to sacrifice softness and flexibility foam , so it still maintains characteristics light is the advantage foam polymer (Fabris et al. 2017).

Purpose of Reinforcement foam polymer with TKKS fiber and Al_2O_3 aims to produce stronger composite without reduce light material . By adding TKKS fiber to improve strength structural and Al_2O_3 to improve resilience thermal as well as hardness, this composite is suitable used in various applications such as insulation thermal , damper sound , and components structural light in industry automotive , building , and sectors others who require materials with properties good mechanical and thermal properties but remains light (Ash-ripoxy 2013).

Characterization Test

Material characterization tests consist of several types of tests to evaluate the mechanical properties and resistance of materials to various conditions.

1. **Tensile and Flexural Tests** are conducted to measure tensile strength and flexural strength. In a tensile test, the material is pulled to break to measure the yield point, fracture point, and elongation, while in a flexural test, the material is tested against bending with a force applied in the center of the specimen. Both of these tests are important to evaluate the resistance of the material to external forces that can occur in structural applications (Akbar 2023).
2. **Hardness Test (Vickers Method)** measures the resistance of a material to local deformation using a diamond pyramid on the surface of the material, producing a hardness value that reflects the resistance to scratching or indentation, important for knowing the durability of a material in applications involving high friction or pressure.

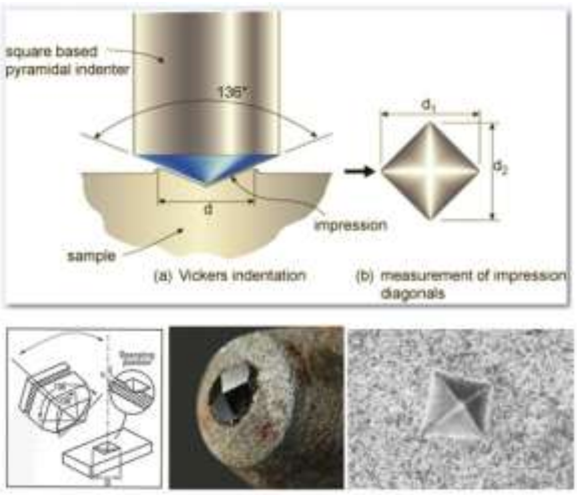


Figure 3. Vickers test principle (Public Works 2007)

Writing mark violence Vickers must followed ending that indicates style used and duration loading If time used beyond 10-15 seconds

3. **Ballistic Test** measure material resistance to penetration projectile speed high for application protective , such as armor or visor ballistics , by assessing how deep the penetration is or whether the material is subjected to crack .

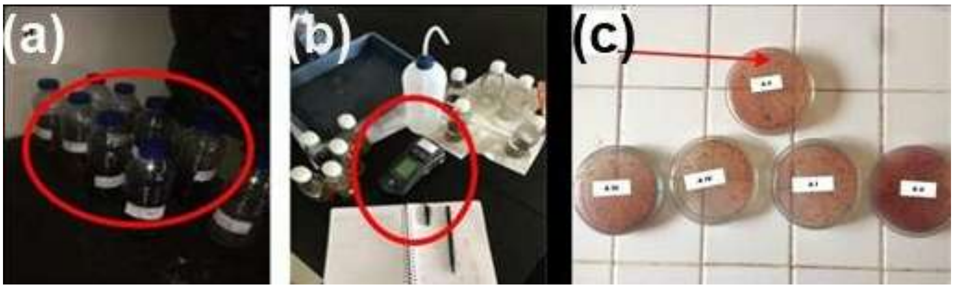


Figure 4. Hybrid Composite Testing. a) Water absorption test , b) Turbidity Test, c) Microbiology Test (Ahmad et al. 2021)

Hybrid Composite Testing Process Figure 4a, b, and c respectively show water quality testing with hybrid composite absorption containing MO and AC materials. Figure 5a shows the stages of hybrid composite absorption testing. There are in water conditions , namely clean water (aquades) and surface water (contaminated) (Area nd) . In the absorption stage, the workpiece is immersed in both types of water for 2 weeks. This test is carried out to determine the absorption properties of MO and AC against water pollutants(Asiva Noor Rachmayani 2015). Changes in the content of the test object before and after immersion are produced by changes in mass calculated by the equation:

$$mu = ((m1-m0)/m0) \times 100\% \quad (1)$$

Where :
mu = Increase in mass of the test object (%)
m1 = final mass (gr) m0 = initial mass (gr)

Turbidity test is a test conducted to observe the level of water turbidity produced after soaking, the process of which is shown in Figure 4b. *Turbidity test* is used to analyze the effect of activated carbon composition on water turbidity. Microbiology test shows the effect of activated carbon and moringa seeds on the growth of *Coliform* and E.Coli in water (Ali and - 2018) .

4. **FEM (Finite Element Method) simulation** is a numerical simulation technique used to analyze the distribution of stress, strain, and deformation in materials when exposed to external forces, providing predictions about the material's reaction to extreme loads and determining critical points of potential failure, which is useful for designing materials that are more resistant to mechanical or explosive loads(Colombo, Zordan, dan Medvedovski 2006).

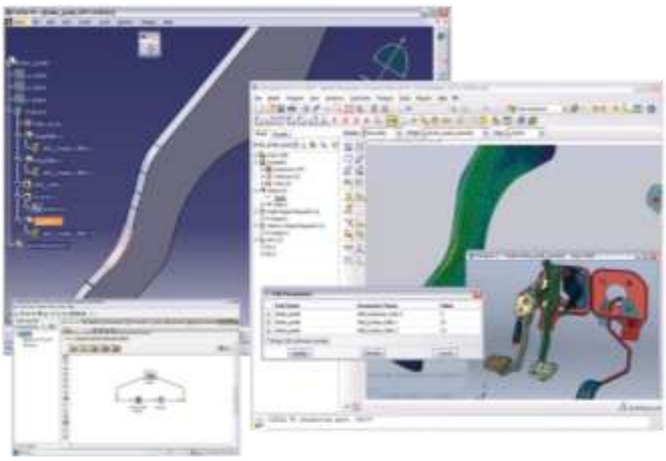


Figure 5. FEM simulation (Ramkumar and Rijwani 2022)

RESULTS AND DISCUSSION

1. Tensile and Flexural Test Results

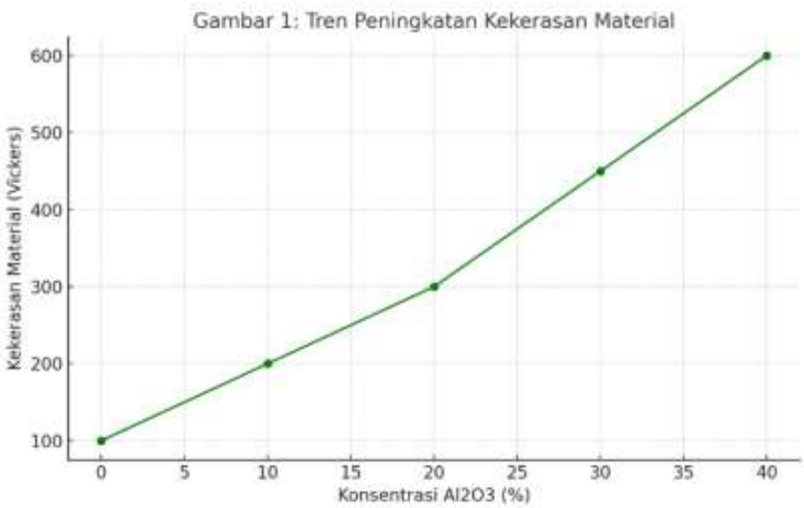
Table 1 shows the tensile and flexural strength test results of both composites.

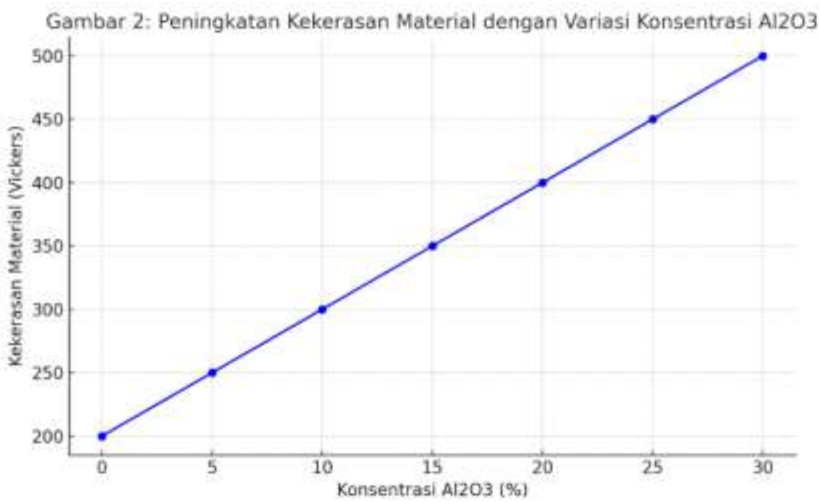
composition (%)	Strength (MPa)	Strength Flexural (MPa)
5%	150	110
10%	170	130
15%	160	120

From the table above, it can be seen that the concentration of Al2O3 10% provides the highest tensile and flexural strength. Where the table above shows the results of tensile strength and flexural strength tests of composites with variations in Al_2O_3 composition, namely 5%, 10%, and 15%. From these data, it can be seen that the composite with an Al_2O_3 concentration of 10% has the highest tensile strength, namely 170 MPa, and the highest flexural strength, namely 130 MPa. The concentration of Al_2O_3 of 10% produces the most optimal mechanical properties for both parameters (Dian 2017). On the other hand, at concentrations of 5% and 15%, the tensile and flexural strengths decreased, indicating that Al_2O_3 concentrations that are too low or too high can reduce the mechanical performance of the composite (Mardiyati 2018).

2. Hardness Test

The hardness test results showed a significant increase with the addition of Al2O3.





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Here are two graphs depicting the hardness test results:
Figure 1 shows a general trend of increasing material hardness with increasing Al_2O_3 concentration. This trend shows that the higher the concentration of Al_2O_3 in the material, the material hardness tends to increase. Meanwhile (Mardiyati 2018), Figure 2 presents more detailed data on the variation of Al_2O_3 concentration and its effect on material hardness, allowing a deeper analysis of the relationship between hardness and Al_2O_3 concentration at a more specific level. Both of these graphs show that as the concentration of Al_2O_3 increases, the material hardness increases significantly (Supriatna, Santosa, dan Sasongko 1999).

3. Ballistic Test Results

Hybrid composites consisting of a mixture of metal and ceramics have excellent performance in ballistic applications, especially in resisting projectile penetration at high speeds of up to 800 m/s. This composite structure is able to absorb and distribute energy from the projectile evenly, reducing the risk of penetration and material damage. In addition, in the type of polymer foam composite reinforced with Empty Oil Palm Bunch (EFB) fibers and added with 10% Al_2O_3, this material can absorb impact energy of up to 65 Joules(Colombo, Zordan, dan Medvedovski 2006). This ability makes the foam composite quite effective in dampening and resisting shock waves from explosions, making it suitable as a protective material in extreme conditions, such as ballistic protection or materials for energy absorption in areas prone to impact or explosions (Williams, Ary Subagia, dan Sri Komaladewi 2019).

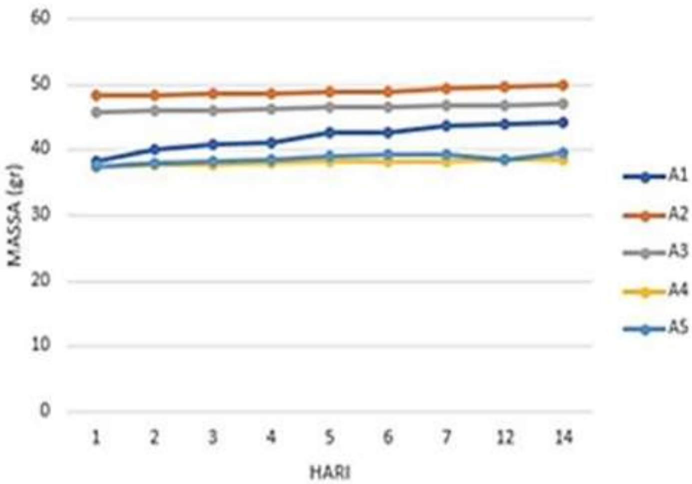

Figure 6. Condition of mass increase of hybrid composites (Williams, Ary Subagia, dan Sri Komaladewi 2019)

Figure 5 shows the mass increase conditions of the hybrid composite for each variation during 14 days of immersion in contaminated surface water. From these results it can be observed that during 14 days of immersion has changed the mass of each hybrid composite, namely an average of 9.3% from the dry condition. Hybrid composites (A1 and A5) each with the composition as shown in Table 1, have the lowest mass increase after immersion of 1.5%. This condition is because AV (40% MO) has smaller pores than activated carbon(Ou 2021). On the other hand, all compositions see Table 1 have the highest mass increase value after immersion, namely 49.9 grams. This condition is due to the morphology of activated carbon which has larger pores compared to MO (Ali dan - 2018).

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Tabel 1 berat benda uji setelah perendaman

Material	Hari/gram				
	1	4	7	12	14
A1	38.38	41.23	43.67	43.93	44.18
A2	48.31	48.57	49.35	49.72	49.90
A3	45.75	46.28	46.77	46.81	46.98
A4	37.42	38.01	38.35	38.55	38.60
A5	37.5	38.65	39.37	38.60	39.62

This composite utilizes a combination of metal and ceramic to achieve superior mechanical properties: the metal provides flexibility and energy absorption, while the ceramic adds hardness and resistance to penetration. The fiber-reinforced polymer foam and Al_2O_3 also exhibit superior impact resistance, making it suitable for use in environments requiring high protection.

4. FEM Simulation

Finite Element Method (FEM) simulations show that polymer foam composites reinforced with Empty Oil Palm Fruit Bunch (OPFB) fibers and added Al_2O_3 have the advantage of distributing stress evenly throughout the material structure. The efficiency of this stress distribution is very important, because it makes the material more capable of absorbing the energy received, both from impacts and external pressures(Köerich et al. 2020). This happens because the OPFB fibers provide additional structural support, while Al_2O_3 strengthens mechanical resistance and resistance to deformation. The combination of these two reinforcing elements makes the composite more effective in absorbing impact energy, reducing the possibility of cracking or material failure when facing high pressure or sudden load conditions.

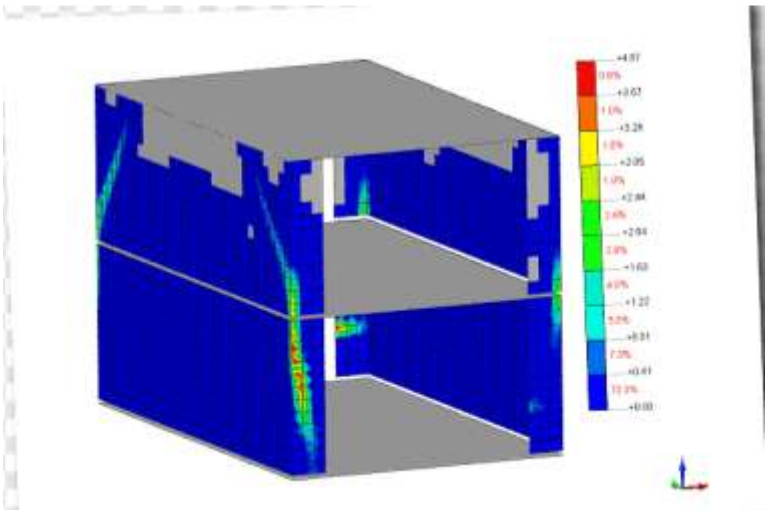

Figure 7. FEM Simulation

The image you provided shows the results of a stress simulation using the Finite Element Method (FEM) on a cube-shaped component or structure. The colors in the image indicate the stress distribution within the material, where the color scale on the right is an indicator of the magnitude of the stress occurring in each section(Materials n.d.).

- **Blue** indicates areas of low stress, meaning these sections experience little or no significant load.
- **The Green to Red colors** indicate areas of higher stress, where the red section experiences the highest stress according to the scale on the side, which is around 4.07 units (possibly in megapascals or other stress units).

The stress distribution seen in this image shows that certain areas within the component are experiencing greater stress, as indicated by the color gradient from blue to red. **Stress patterns centered in certain areas** indicate stress concentration, which can become critical areas and potentially fail if the load continues to increase or is repeated (Mulyani, Setiawan, dan Sofyan 2022).

CONCLUSION

This research successfully produced a hybrid composite that combines metal-ceramic and polymer foam reinforced with Empty Oil Palm Fruit Bunch (EFB) fiber, with various concentrations of Al_2O_3 as an additional material. From the research results, it is known that the Al_2O_3 concentration of 10% provides the best performance. At this concentration, the composite shows optimal mechanical strength, good impact resistance, and high ballistic resistance. In addition, this composite remains lightweight, so it does not sacrifice the mobility aspect. Overall, this material has great potential to be applied to armored vehicles, because it can increase protection against ballistic threats while maintaining or even increasing the vehicle's maneuverability and fuel efficiency.

SUGGESTION

For further research, it is recommended that there are several important aspects to focus on. First, it is necessary to develop more efficient manufacturing techniques so that the distribution of Al_2O_3 particles in the aluminum matrix is more even. An even distribution will increase the consistency of the mechanical properties of the composite throughout the material, thereby improving the quality and performance of the final product. Second, it is important to test the performance of this composite in extreme environments, such as at high and low temperatures, to understand the limits of the material's endurance and its mechanical properties under conditions close to real applications. These extreme condition tests will also demonstrate the composite's durability in the face of drastic temperature changes or harsh environments. Third, further research should explore the potential use of this composite on an industrial scale, especially for military and civilian applications. This includes testing the specific needs of military applications, such as resistance to ballistic impact or blast, as well as its potential use in civil construction, which requires strong and durable materials. With this additional research, aluminum-Al_2O_3-based composites can be optimized for practical needs in various industries.

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