Journal of Renewable Engineering
E-ISSN : 3046-7624
https://nawalaeducation.com/index.php/JORE/index
Vol.2.No. 1 February 2025
DOI : https://doi.org/10.62872/17a64y42

SWOT Analysis of the Effect of New Materials on Engine Performance and Durability

Anauta Lungiding Angga Risdianto[1], Rahmad Surya Hadi Saputra[2], Muh Thohirin [3], Jacky Chin[4]
Politeknik Negeri Madura, Indonesia[1], Politeknik Kelautan dan Perikanan Karawang, Indonesia[2], Universitas Sang Bumi Ruwa Jurai, Indonesia [3], Universitas Mercu Buana, Indonesia[4]

Email : anggarisdianto48@gmail.com

Received: January 01, 2025
Revised : January 31, 2025
Accepted: Feberuary 02, 2025
Published: Februari 05, 2025

ABSTRACT

Material innovation in the manufacturing and automotive industries plays an important role in improving engine performance and durability. Conventional materials such as steel and aluminum have limitations in resistance to extreme temperatures and wear, so new materials such as high-performance metal alloys, carbon fiber composites, and nanotechnology-based materials are developed as solutions. These materials are capable of improving energy efficiency, reducing weight, and extending component life. However, the adoption of new materials faces challenges such as high production costs, fabrication complexity, and validation in real operational environments. Therefore, collaboration between academia, industry and government is needed to develop solutions that are not only technically superior, but also economical and sustainable. This research uses the SWOT method to analyze the strengths, weaknesses, opportunities, and threats in the application of new materials. Data were obtained through literature studies, laboratory experiments, and expert interviews. The analysis results show that materials such as carbon fiber composites (CFRP) have advantages in fuel efficiency and corrosion resistance, but also face challenges in production and maintenance costs. With innovations in manufacturing technology and a more sustainable approach, new materials have the potential to be the optimal solution for the automotive and manufacturing industries in the future.

Keywords: Engine Performance and Durability; New Materials; SWOT

INTRODUCTION

In the manufacturing and automotive industries, material innovation is an essential factor in improving engine performance and durability. Conventional materials such as steel and aluminum, although widely used, have limitations in terms of resistance to extreme temperatures, wear and tear, and energy efficiency. Therefore, the development of new materials such as high-performance metal alloys, carbon fiber-reinforced polymer composites, and advanced ceramic materials is a solution to overcome these limitations. Studies by Korkmaz et al (2022) show that materials with superior mechanical properties, such as titanium alloys or nickel-based superalloys, can improve engine thermal efficiency and extend component life. Thus, the exploration of new materials is not just an innovation, but also an urgent need to improve industrial competitiveness.

On the other hand, the adoption of new materials in machine technology does not always go without challenges. High production costs, difficulties in the fabrication process, and the need for more complex design methods are major barriers to the adoption of innovative materials. For example, composite materials that have high strength-to-weight ratios, such as carbon fiber composites, often require special manufacturing techniques, such as autoclave curing or carbon fiber-based additive manufacturing, which add significantly to production costs (Wulandari, 2023). In addition, the process of validating new materials in real operational environments takes time and extensive research to ensure their reliability. Therefore, collaboration between academia, industry and government is needed to develop solutions that are not only technically superior, but also economical and sustainable.

New material developments in mechanical engineering focus not only on improving strength and durability, but also on weight optimization and energy efficiency. Materials such as carbon fiber and aluminum-lithium alloys are now widely used in the automotive and aerospace industries to reduce mass without sacrificing structural strength (Siengchin, 2023). This weight reduction has direct implications for fuel efficiency and overall engine performance, especially in electric vehicle and aircraft applications. In addition, nanotechnology-based materials such as graphene-reinforced composites show tremendous potential in improving thermal conductivity and corrosion resistance, which can extend the life of engine components in extreme working environments. Therefore, research is constantly evolving to explore materials that are not only lightweight and strong, but also capable of improving overall system efficiency.

However, while new materials offer various advantages, technical challenges in their processing remain a major obstacle to industrial implementation. Carbon fiber-based composites, for example, often have difficulties in joining and repairing compared to conventional metals, requiring advanced manufacturing techniques such as resin transfer molding or additive manufacturing (Bagaskoro et al., 2021). In addition, the anisotropic nature of some composite materials demands more complex design and simulation methods in order to accurately predict their mechanical behavior under various operating conditions. Therefore, a multidisciplinary approach combining materials science, manufacturing engineering, and numerical computing is needed to ensure that new materials not only provide theoretical advantages, but can also be effectively applied in the mechanical engineering industry.

The working efficiency of a machine is greatly influenced by the physical and mechanical properties of the materials used in each of its components. One of the main factors determining efficiency is the coefficient of friction between components, which directly affects energy consumption and mechanical wear. Materials with superior tribological properties, such as DLC (Diamond-Like Carbon) based protective coatings or metal alloys with solid lubricants such as MoS_2, have been shown to significantly reduce friction and improve energy efficiency in machinery systems (Fuadi & Rahmadiawan, 2023). In addition, materials with high thermal conductivity, such as copper-beryllium or graphene-based composites, can improve heat dissipation in high-performance engines, reduce the risk of overheating, and extend component life (Pilali et.al., 2025). Therefore, proper material selection not only improves operational efficiency but also reduces maintenance costs in the long run.

Material fatigue resistance is also a critical factor in extending engine life, especially in components subjected to high dynamic loads such as crankshafts, bearings and turbines. Conventional materials such as carbon steel often fail due to cyclic loading which causes micro-cracking and eventually structural failure. As a solution, the use of nickel-based superalloys, titanium, or carbon fiber composite materials has shown significant improvements in material fatigue resistance (Putri et al., 2022). In addition, material engineering techniques such as heat treatment, shot peening, and ceramic-based coatings can improve resistance to microstructural degradation that occurs during long-term use (Kumar et.al, 2019). Thus, material innovation not only plays a role in instantly improving engine performance, but also contributes to reliability and longer service life, which ultimately impacts cost efficiency in the manufacturing and automotive industries.

While new material innovations carry great potential in improving engine performance and durability, the challenges in their application cannot be ignored. One of the main obstacles is the high production cost, especially for advanced materials such as nickel-based superalloys or carbon fiber composites, which require special manufacturing processes with high-tech equipment. According to Nurul et al (2024), the high cost of raw materials as well as complexity in production processes, such as additive manufacturing or high-temperature processing techniques, are the main factors limiting the adoption of new materials in large-scale industries. In addition, innovative materials often face obstacles in integration with existing machine systems, requiring design modifications as well as extensive testing to ensure compatibility under real operating conditions. Therefore, the development of more efficient and economical manufacturing technologies is key in accelerating the transition to new materials.

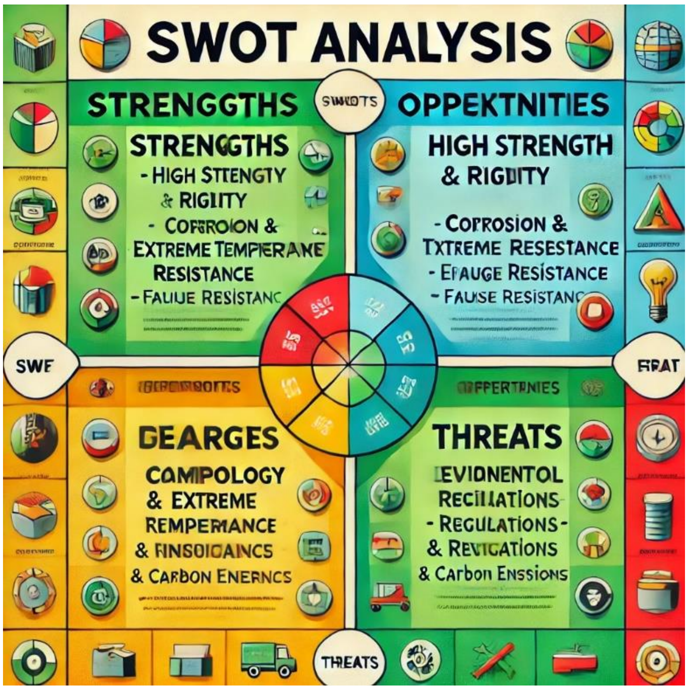
In addition to technical and cost challenges, sustainability and environmental impact are also important factors in the utilization of new materials. Some advanced materials, such as rare earth-based metal alloys, have limitations in terms of resource availability as well as the ecological impact of their extraction and processing processes (Zainul., 2024). This demands a more sustainable approach to materials development, including the exploration of alternatives based on recycled materials or biomaterials that are more environmentally friendly. In addition, increasingly stringent environmental regulations, such as the European Union's policy on carbon emissions in the manufacturing industry, encourage companies to seek material solutions that are not only technically superior, but also meet global sustainability standards. As such, the future prospects for new materials depend largely on the balance between technical excellence, cost efficiency, and their impact on the environment and the availability of natural resources

METHOD

This research uses the SWOT (Strengths, Weaknesses, Opportunities, and Threats) method to analyze the effect of new materials on engine performance and durability. Data were obtained through literature studies, laboratory experiments, and expert interviews. The SWOT analysis included identification of new material strengths, such as wear resistance and thermal efficiency; weaknesses, including manufacturing costs and integration challenges; opportunities, such as applicability in the automotive and aerospace industries; and threats, such as environmental regulations and competition with conventional materials.

The results of the analysis are used to assess the feasibility of implementing new materials, provide strategic recommendations, and design future research directions for the development of more efficient and sustainable materials. This approach ensures material innovation can adapt to industry needs and global challenges.

Figure 1. Analysys SWOT CFRP



RESULT AND DISCUSSION

RESULT

1. **Strengths**

Carbon fiber composites have a number of strengths that make them a superior choice in the development of material technology for engines. First, the lightweight yet strong properties of carbon fiber composites provide significant advantages in improving engine performance, such as fuel efficiency and transportability. With high strength yet lighter weight compared to traditional metal materials, these composites allow for a reduction in the overall weight of the engine, which in turn optimizes performance. In addition, carbon fiber composites also have outstanding resistance to corrosion. Unlike metals that are prone to corrosion in damp or harsh environmental conditions, these composites retain their quality and strength over the long term, making them more durable and reducing maintenance requirements. Another property is high tolerance to extreme temperatures. Carbon fiber composites remain stable and strong even when subjected to high temperatures or pressure, which is especially important for machine applications that operate in hot conditions or require resistance to high temperatures. Finally, their design flexibility allows them to be produced in a variety of complex shapes, providing more options in designing and developing more efficient and innovative machines. With these advantages, carbon fiber composites make a major contribution to improving engine performance and durability, especially in applications that require high strength, durability, and efficiency.

2. **Weaknesses**

Although carbon fiber composites have many advantages, there are some disadvantages that can limit their use in the machinery industry. One of the main disadvantages is the relatively high production cost compared to traditional metallic materials. This high cost includes complex manufacturing processes and specific raw materials, which can limit their adoption in industries with limited budgets, especially in sectors that are more conservative or require low-cost solutions. In addition, carbon fiber composites also face difficulties in maintenance and repair. In the event of damage, they are more difficult to repair compared to metals or other materials, which can lead to higher maintenance costs and delays in the recovery process. The manufacturing process of carbon fiber composites is also quite complex, requiring more advanced production techniques and specialized equipment, which in turn can hinder the application of mass production scale. Finally, despite their extremely high tensile strength, carbon fiber composites are susceptible to damage from impact or high local stresses. This makes these materials less than ideal for applications involving hard impacts or extremely rough environmental conditions, potentially reducing their durability in certain situations. Thus, while carbon fiber composites offer many advantages, these drawbacks need to be carefully considered in the decision-making process for their application in industry.

3. Opportunities

Carbon fiber composites offer a promising range of opportunities in various industries. One of the main opportunities lies in their use in the automotive and aviation industries. The need for lightweight yet strong materials to improve fuel efficiency and performance makes carbon fiber composites highly relevant, especially amidst the competition to create more efficient and environmentally friendly vehicles. In addition, innovations in the production process of carbon fiber composites are a great opportunity to reduce costs and accelerate their adoption in other industrial sectors. With new technologies that are more efficient and affordable, these materials have the potential to be used more widely in various applications. As awareness of environmental impacts increases, carbon fiber composites also have a great opportunity to become a key choice in supporting sustainability. These materials, which are lighter and more durable, can help reduce energy consumption and waste in various industrial sectors. In addition, carbon fiber composites have great potential in the development of electric vehicles, where their use in electric engines and components can improve efficiency, extend mileage, and reduce energy consumption, contributing significantly to the development of greener electric mobility. With these opportunities, carbon fiber composites show great potential to change the way we design and manufacture the engines and components of future technologies.

4. Threats

Carbon fiber composites, despite their numerous advantages, also face several threats that may limit their adoption in industry. One of the biggest threats is competition from alternative materials that offer similar advantages at a lower cost, such as titanium, aluminum, or glass fiber-based plastics. These materials can be a more economical option for industries that prioritize low production costs, which can threaten the dominance of carbon fiber composites in the market. In addition, fluctuations in the price of raw materials, especially carbon fiber itself, can affect production costs and the sustainability of using this material. This volatility in raw material prices may make long-term planning difficult and increase production costs unexpectedly. Increasingly stringent industry regulations and standards can also be a barrier to the adoption of carbon fiber composites, especially in sectors that require certification of materials to very high standards. Complicated certification processes and strict regulatory requirements can slow down the adoption of these materials in some industry sectors. Finally, the limitations of expensive and complex production infrastructure for manufacturing carbon fiber composites may hinder their development and widespread application. The construction of adequate production facilities requires large investments and long lead times, which may slow down the scale of mass production and adoption of these materials in various machinery applications. Thus, these threats should be carefully considered in the future development strategy of carbon fiber composites.

DISCUSSION

Carbon fiber composites (CFRP) are known to have tremendous potential in high-performance engine applications due to their various advantages, such as extremely high strength, light weight, and corrosion resistance (Hegde et al., 2019). CFRP is able to withstand significant mechanical loads while reducing weight, making it an ideal material for the automotive and aviation industries. The use of CFRP in these industries is crucial as it can improve fuel efficiency and overall performance. For example, in a study by Parapat et al. (2025), it was revealed that these composites have excellent mechanical properties, as well as resistance to high temperatures and extreme pressure, which makes them particularly suitable for use in engine components that require high durability.

In a further context, CFRP is becoming a very attractive material in the development of engine components such as aircraft turbines and high-performance automobile engines. Its ability to provide high structural strength without adding excessive weight gives it a competitive advantage in industries that rely heavily on material performance. Scientifically, CFRP's ability to cope with the combination of extreme thermal and mechanical stresses at high temperatures is critical for such applications. Studies have shown that CFRP not only improves engine performance, but also extends the service life of components made from this material, resulting in cost savings and improved safety in these applications (Ahmad et.al., 2020).

Although CFRP (Carbon Fiber Reinforced Polymer) offers a number of advantages, such as high strength and light weight, there are some significant drawbacks that hinder its widespread adoption in industry. One of the main obstacles is the very high cost. Ozkan al. (2020) noted that carbon fiber composites can cost ten to twenty times more than conventional metal materials such as aluminum or steel. This makes CFRP a less economical option, especially for mass production where cost efficiency is a priority. This cost restriction is often a major barrier to the utilization of CFRP in more cost-sensitive industrial sectors, such as automotive and construction.

In addition to the cost issue, the production process of CFRP is also quite complicated and requires high technology, which slows down scalability and reduces the ability to produce these materials in large quantities. This complex manufacturing process not only increases the initial cost but also makes it difficult to maintain and repair CFRP, which is more difficult compared to metallic materials. Some studies have shown that damage to carbon fiber composites can require specialized repair techniques that are expensive and not always easily feasible (Eka et.al., 2021) Therefore, although CFRP offers tremendous potential in terms of performance, challenges related to cost, manufacturing process, and maintenance remain major barriers to its widespread adoption.

Nonetheless, the opportunities for the development of CFRP (Carbon Fiber Reinforced Polymer) remain enormous, especially with the increasing demand for environmentally friendly and fuel-efficient materials. Carbon fiber composites have lightweight and durable properties, which make them an excellent alternative to replace metals in various engine components. This can have a positive impact on reducing fuel consumption and greenhouse gas emissions, as evidenced by the research of Prenzel et al. (2023). CFRP materials can reduce vehicle weight and improve fuel efficiency, which is highly relevant in the automotive and aerospace industries. In a scientific context, vehicle weight reduction using CFRP has been shown to improve thermal and mechanical efficiency, which in turn contributes to the reduction of CO2 emissions in transportation systems.

In addition, innovations in more efficient CFRP production technologies, such as the use of bio-based resins or faster production methods, are expected to lower production costs and accelerate the adoption of these materials in various industry sectors (Andrew & Dhakal, 2022). Bio-resin technology, which is made from organic materials and is more environmentally friendly, can reduce dependence on fossil resources and reduce the environmental impact of CFRP production. The adoption of faster and energy-efficient production methods will also reduce operational costs, making CFRP more affordable for mass applications. From a scientific perspective, research continues to improve the mechanical and thermal properties of CFRP and enhance production techniques, which opens up great opportunities to increase the applicability of this material in various industrial applications, from automotive to construction and aviation.

However, while the development opportunities for CFRP (Carbon Fiber Reinforced Polymer) are immense, the material also faces a number of challenges that need to be addressed. One of these is fierce competition with cheaper alternative materials, such as lightweight metals and composite ceramics (Koumoulus et al, 2019). These materials often offer lower manufacturing costs and competitive performance in some applications. In addition, fluctuations in the price of carbon fiber raw materials, which are heavily influenced by global market conditions, can add uncertainty to the price of the final CFRP product. This factor could make CFRP less competitive when compared to other more affordable materials.

From a scientific perspective, the production cost of CFRP is heavily influenced by the carbon fiber manufacturing process itself, which requires high energy and specialized raw materials. This makes CFRP a more expensive option, especially in mass production. In addition, increasingly stringent environmental regulations, especially regarding the reduction of carbon emissions and the use of environmentally friendly raw materials, can also increase the production cost of CFRP. These policy changes encourage the industry to look for more sustainable raw material alternatives, which could impact the material composition and production process of CFRP, and lead to higher costs or technological changes. Therefore, although CFRP has great potential in various sectors, these factors need to be carefully considered to ensure its competitiveness in the global market.

Overall, carbon fiber composites (CFRP) offer a number of advantages that make them ideal materials for high-performance engine applications. Exceptional strength, light weight, and corrosion resistance make CFRP highly attractive to the automotive, aerospace, and other industries that prioritize efficiency and durability. However, despite its great potential, the adoption of CFRP in the world of high-performance engines is still limited by several factors, most notably its extremely high cost and difficulty in the maintenance process. The production of CFRP, which involves special techniques such as carbon fiber reinforcement through epoxy resin, is a complicated and expensive process, while the maintenance of this material requires special skills to maintain its quality and performance.

However, with the continued development of more efficient production technologies and increasing awareness of the importance of sustainability and fuel efficiency, CFRP has the potential to transform engine design in the future. More innovative manufacturing processes, such as the use of automation-based processing techniques or even the use of more affordable raw materials, can lower the cost and increase the scalability of CFRP production. Furthermore, as the demand for more environmentally-friendly materials increases, CFRP is becoming a highly relevant solution due to its ability to reduce vehicle weight, which in turn leads to better fuel efficiency and lower emissions. As such, companies and technology developers should focus on research and development that can address cost and maintenance challenges, and capitalize on existing opportunities to expand the adoption of CFRP in the engine industry globally

CONCLUSION

Carbon fiber composites (CFRP) offer a number of advantages, such as high strength, light weight, and resistance to corrosion, which are particularly suitable for high-performance engine applications in the automotive and aviation industries. CFRP helps improve fuel efficiency and transportability by reducing engine weight. However, CFRP also faces several disadvantages, mainly high manufacturing costs, complicated manufacturing processes, and difficulties in maintenance and repair. These drawbacks limit the adoption of CFRP, especially in industries with limited budgets. Nonetheless, the opportunity to develop CFRP is still enormous, especially with innovations in more efficient production processes and the application of environmentally friendly technologies. In addition, the use of CFRP in electric vehicles can help improve energy efficiency and reduce emissions. Threats to CFRP include competition with cheaper alternative materials and fluctuations in raw material prices, which can affect production costs and sustainability. CFRP also faces challenges related to strict regulations and expensive production infrastructure. However, with more efficient production technologies and increasing awareness of sustainability, CFRP has the potential to replace conventional materials in various applications. Therefore, further development is required to overcome the cost and maintenance challenges, and capitalize on the existing opportunities to expand the use of CFRP in the industry.

REFERENCES

Ahmad, H., Markina, A. A., Porotnikov, M. V., & Ahmad, F. (2020, November). A review of carbon fiber materials in automotive industry. In *IOP Conference Series: Materials Science and Engineering* (Vol. 971, No. 3, p. 032011). IOP Publishing.

Andrew, J. J., & Dhakal, H. N. (2022). Sustainable biobased composites for advanced applications: recent trends and future opportunities–A critical review. *Composites Part C: Open Access*, *7*, 100220.

Bagaskoro, I., Hidayat, M. I. P., & Ardhyananta, H. (2021). Simulasi Delaminasi Laminat Komposit Serat Karbon terhadap Variasi Arah Serat Menggunakan Teknik Cohesive Zone Model (CZM) dan Virtual Crack Closure (VCC) dengan Metode Elemen Hingga. *Jurnal Teknik ITS*, *9*(2), F272-F277.

Eka Dwi, R. S., SM Bondan, R., & Darmanto, D. (2021). *ANALISIS KEKUATAN TARIK DAN BENDING KOMPOSIT SERAT KARBON-RESIN DENGAN VARIASI WAKTU CURING DAN SUHU PENAHANAN 80C* (Doctoral dissertation, Universitas Wahid Hasyim).

Fuadi, Z., & Rahmadiawan, D. (2023). *Tribologi Pelumasan: Pelumas Terbarukan*. Syiah Kuala University Press.

Hegde, S., Shenoy, B. S., & Chethan, K. N. (2019). Review on carbon fiber reinforced polymer (CFRP) and their mechanical performance. *Materials Today: Proceedings*, *19*, 658-662.

Korkmaz, M. E., Gupta, M. K., Waqar, S., Kuntoğlu, M., Krolczyk, G. M., Maruda, R. W., & Pimenov, D. Y. (2022). A short review on thermal treatments of Titanium & Nickel based alloys processed by selective laser melting. *journal of materials research and technology*, *16*, 1090-1101.

Koumoulos, E. P., Trompeta, A. F., Santos, R. M., Martins, M., Santos, C. M. D., Iglesias, V., ... & Charitidis, C. A. (2019). Research and development in carbon fibers and advanced high-performance composites supply chain in Europe: a roadmap for challenges and the industrial uptake. *Journal of Composites Science*, *3*(3), 86.

Kumar, D., Idapalapati, S., Wang, W., & Narasimalu, S. (2019). Effect of surface mechanical treatments on the microstructure-property-performance of engineering alloys. *Materials*, *12*(16), 2503.

Nurul Hidayat, S. E., Inong Oskar, S. T., Khalid, I. A., Utama, F. Y., Fikri, M. A., Yunus, M. P., ... & Sakti, A. M. (2024). *Eksplorasi Proses Manufaktur Untuk Masa Depan Teknologi Dan Produksi*. Cendikia Mulia Mandiri.

Ozkan, D., Gok, M. S., & Karaoglanli, A. C. (2020). Carbon fiber reinforced polymer (CFRP) composite materials, their characteristic properties, industrial application areas and their machinability. *Engineering Design Applications III: Structures, Materials and Processes*, 235-253.

Parapat, R. Y., Rudiyanto, R., Taryana, M. R. I., Aprilian, P. F. D., & Mubarok, M. S. (2025). Nanoteknologi dalam Desain dan Pengembangan Komponen Ringan untuk Pesawat Terbang. *Scientica: Jurnal Ilmiah Sains dan Teknologi*, *3*(3), 717-738.

Pilali, E., Soltani, M., Hatefi, M., Shafiei, S., Salimi, M., & Amidpour, M. (2025). Passive thermal management systems with phase change material-based methods for lithium-ion batteries: A state-of-the-art review. *Journal of Power Sources*, *632*, 236345.

Prenzel, T. M., Hohmann, A., Prescher, T., Angerer, K., Wehner, D., Ilg, R., ... & Albrecht, S. (2023). Bringing Light into the Dark—Overview of Environmental Impacts of Carbon Fiber Production and Potential Levers for Reduction. *Polymers*, *16*(1), 12.

Putri, N. M. K. A. I., Aritonang, S., & Sudiro, T. (2022). PEMILIHAN MATERIAL PELAPISAN UNTUK PENINGKATAN DAYA TAHAN BILAH TURBIN PESAWAT. *Jurnal Teknologi Daya Gerak*, *5*(1), 51-61.

Siengchin, S. (2023). A review on lightweight materials for defence applications: Present and future developments. *Defence Technology*, *24*, 1-17.

Wulandari, F. (2023). *Analisa Sifat Mekanis Pada Material Komposit Serat Karbon Dan Resin Epoxy Dengan Variasi Laminasi* (Doctoral dissertation, ITN MALANG).

Zainul, R. (2024). *Elektrokimia dalam Pembuatan dan Karakterisasi Bahan Berbasis Karbon*. PT. RajaGrafindo Persada-Rajawali Pers..