SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmujournal.com.my/index.php/aram/index
ISSN: 2289-7895

Mechanical Properties of Composite from Roving Fibre and Polyester Resin BQTN R157 Variations Manufactured using Vacuum Bagging Method for Unmanned Aerial Vehicle Applications

Bambang Setiawan[1], Rasma[2], Anwar Ilmar Ramadhan[1,*], Reza Febriano Armas[2], Thomas Junaedi[2], Abdul Hamid Hamisa[3]

1 Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, Jakarta 10510, Indonesia
2 Department of Automotive and Heavy Equipment Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, Jakarta 10510, Indonesia
3 Faculty Technology, Design and Management, UCYP University, 25050 Kuantan, Pahang, Malaysia

ARTICLE INFO

Article history:
Received 16 March 2025
Received in revised form 19 April 2025
Accepted 26 April 2025
Available online 30 May 2025

Keywords:
Composite; fibre; mechanical properties; reinforced; tensile

ABSTRACT

A study on the mechanical properties of roving fibre-reinforced polyester resin composites was conducted, focusing on tensile tests with fibre orientations of 0°, 90° and 45°. The composite was fabricated with a fibre-to-resin mass fraction of 60%:40%. The objective of this research was to analyse the micro and macro properties of roving fibre composites with polyester resin for unmanned aerial vehicle (UAV) applications. Micro properties were evaluated through density testing, while macro properties were determined via tensile strength testing following ASTM D3039 standards. The UAV application was further analysed against the atmospheric pressure and altitude requirements based on the International Standard Atmosphere. Composite fabrication employed the vacuum bagging method with a consistent 60% fibre and 40% resin volume fraction. Results indicated that the highest density, 1.844 g/cm³, was achieved with a 45° fibre orientation. The study revealed that increased fibre content corresponds to higher composite density. Tensile tests demonstrated that the highest tensile modulus of 25,255.33 MPa, was obtained with a 90° fibre orientation. Atmospheric pressure analysis for UAVs showed that the 90° fibre-oriented composite exhibited superior strength compared to air pressure, achieving a maximum stress of 641.96 MPa. These findings confirm that the composite with a 90° fibre orientation meets the required air pressure standards for UAV construction, demonstrating high suitability for such applications.

1. Introduction

The use of composite materials in the construction of unmanned aerial vehicle airframes has gained significant attention in recent years due to their ability to provide high specific strength and stiffness, which can contribute to improved flight performance and increased payload capacity [1].

* *Corresponding author.*
E-mail address: anwar.ilmar@umj.ac.id

https://doi.org/10.37934/aram.137.1.5866

This study aims to investigate the tensile strength characteristics of a composite laminate fabricated using a vacuum bagging method [2,3], with a focus on the impact of variations in the roving fibre and polyester resin BQTN R157 composition on the material's mechanical properties [4-6].

The research draws upon previous studies that have explored the optimization of composite airplane fuselages for structural integrity [7,8], the development of high-strength lightweight sandwich composites for load-bearing applications [9,10] and the potential use of natural fibres in UAV airframe construction [11,12]. The current investigation provides a comprehensive evaluation of the tensile strength of the composite laminate, which is a critical requirement for the design and fabrication of UAV airframes [13-15].

The composite laminates were fabricated using the vacuum bagging method, which offers advantages in terms of improving the quality and consistency of the final product by reducing the presence of voids and ensuring effective bonding between the reinforcing fibres and the resin matrix. The tensile strength of the laminates was then evaluated through a series of standardized tests, with the results analysed to determine the optimal combination of roving fibre and polyester resin BQTN R157 for UAV applications [16,17]. Based on the identified problems, the research question addressed in this study is to what extent do variations in pressure and temperature changes at different flight altitudes affect the mechanical strength in tensile testing with different fibre orientation variations (0°, 90° and 45°) and which fibre orientation exhibits the best performance [18,19].

Roving fibre refers to a bundle of strands (typically 20) arranged without twisting and wound onto a spool. Releasing the winding from the inside of the spool may cause it to twist by 2–5 turns per meter. Glass fibres come in various types, including E-glass, A-glass, C-glass, D-glass, S-2 glass, R-glass, T-glass, low K and hollow fibre. E-glass is a type of fibreglass with low alkali glass concentration and consists of aluminium borosilicate, exhibiting excellent electrical insulating properties. It is widely used in the industry due to its cost-effectiveness [20-29] for sample roving in Figure 1. In this study, the fibre used is E-glass roving fibre with orientations of 0°, 90° and 45°, which are then stacked and combined with two different fibre directions.

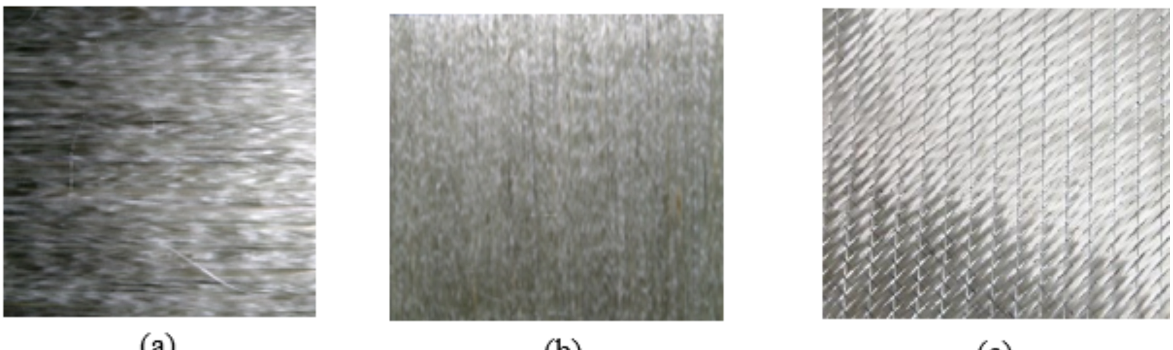


Fig. 1. (a) 0° roving fibre (b) 90° roving fibre (c) ±45° roving fibre [21]

2. Methodology
2.1 Material

The research begins with an extensive literature study to establish a theoretical framework and gather essential knowledge regarding materials, tools and relevant testing standards. The next step involves measurement and cutting of the raw materials. The roving fibres are cut into dimensions of 30 x 30 cm, producing 258 individual pieces. Additional materials such as Peel Ply fabric (40 x 40 cm, 1 sheet), Breather cloth (40 x 40 cm, 2 sheets) and Plastic bagging (80 x 80 cm, 1 sheet) are prepared.

The polyester resin and catalyst are mixed in a 2:1 ratio, ensuring proper bonding and curing properties. Further, sealant tape (4 m, 1 roll) and release wax are utilized to maintain vacuum sealing during the bagging process. the research concludes with a summary of findings in the conclusions and recommendations section, offering insights and suggestions for future studies or practical applications. This structured and methodical approach ensures the validity and reliability of the research outcomes, providing a thorough understanding of the composite material's mechanical behaviour under specified conditions.

The cut roving fibres were then measured for their mass using a digital scale. By applying a mass fraction ratio of 60% filler to 40% matrix, the estimated mass of the composite material was determined. Once the resin mass was obtained, it was further divided using a ratio of 99:1, which represents the proportion between polyester and the catalyst. The composite material was fabricated using the vacuum bagging method, aiming to minimize the presence of trapped air during the hand lay-up process. The vacuum process was carried out for 2 hours, while the drying process required 1 day to achieve optimal results. The materials used in this process are presented in Table 1.

Table 1
Materials in this research

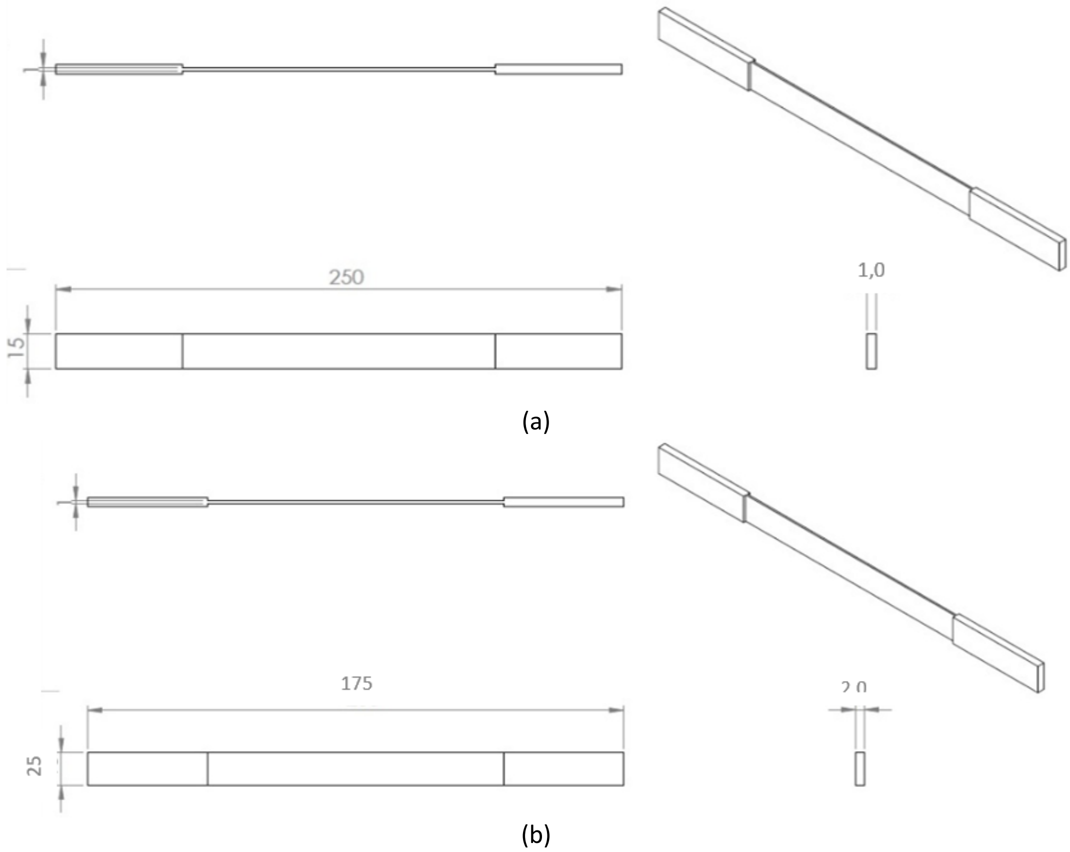
No.	Material	Size	Quantity
1	Roving fibre	(30 x 30) cm	258 sheets
2	Peel Ply fabric	(40 x 40) cm	1 sheet
3	Breather cloth	(40 x 40) cm	2 sheets
4	Plastic bagging	(80 x 80) cm	1 sheet
5	Polyester and Catalyst	2:1 ratio	-
6	Sealant tape	4 m	1 roll
7	Release wax	-	1 unit

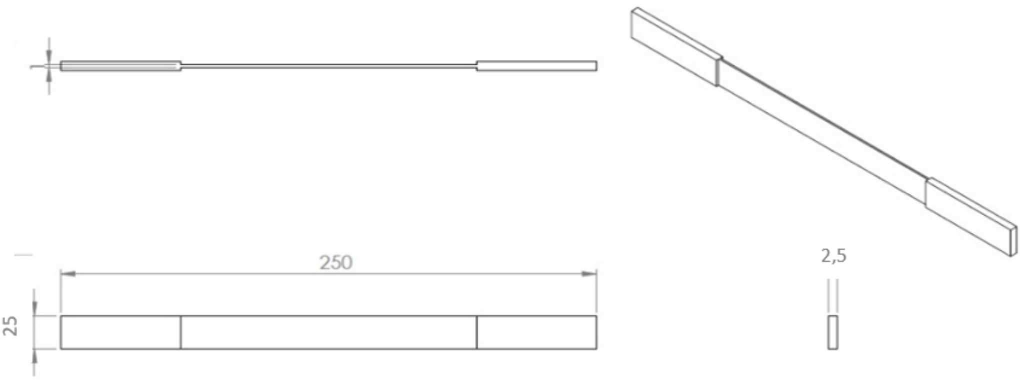
2.2 Procedure

The specimen testing was divided into two categories: physical testing, which included density testing (specimen density) and mechanical testing, which included tensile testing in accordance with the ASTM D-3039 standard [23]. The composite material specimens were first tested for density using a density meter. For tensile testing, a Universal Testing Machine (UTM) Tensilone was used (Figure 2). This equipment is capable of performing various tests, including tensile, compression and shear tests. The tensile testing results provided data on the material's strength in uniformly withstanding axial loads [24,25].

Fig. 2. UTM Tensilone RTF-2410 15 [25]

The mechanical property testing conducted focused on the tensile strength of roving/polyester composite materials. This testing utilized variations in fibre orientation, specifically 0°, 90° and 45°, as illustrated in the Figure 3.





(c)

Fig. 3. Specimen (a) 0°, (b) 90° and (c) 45°

3. Results

3.1 Density for Materials

The results of density testing using a densitometer for the samples are shown in the table below. These results provide valuable insights into the material properties of each sample, allowing for comparative analysis and further interpretation regarding uniformity, material composition or potential applications. Table 2 illustrates the density testing results for composite specimens oriented at 90°. The data includes the mass of the specimens in air and water, as well as the calculated densities of water and the composite specimens. The average density of the composite with a fibre fraction of 60% and a resin fraction of 40% was determined to be 1.844 g/cm³. This testing demonstrates the consistency of the composite's density values, with minor variations across the five specimens.

Table 2
Density test results at 90°

Specimen	Mass in Air (gr)	Mass in Water (gr)	Water Density (g/cm³)	Specimen Density (g/cm³)
1	0.8307	0.3819	0.97737	1.806
2	0.8720	0.3890	0.97737	1.844
3	0.9685	0.4332	0.97737	1.817
4	0.9286	0.4233	0.97737	1.846
5	0.9365	0.4377	0.97737	1.886
Average	-	-	-	1.844

Table 3 shows the results of density testing for composite specimens oriented at 0°. The measurements include the mass of each specimen in air and water, along with the calculated densities of water and the specimens. The average density of the composite with a fibre fraction of 60% and a resin fraction of 40% was determined to be 1.6484 g/cm³.

Table 3
Density test results at 0°

Specimen	Mass in Air (gr)	Mass in Water (gr)	Water Density (g/cm³)	Specimen Density (g/cm³)
1	0.1858	0.0828	0.97737	1.796
2	0.3159	0.1222	0.97737	1.622
3	0.2956	0.1133	0.97737	1.611
4	0.3165	0.1144	0.97737	1.554
5	0.3118	0.1255	0.97737	1.666
Average	-	-	-	1.6484

Table 4 illustrates the density testing results for composite specimens oriented at 45°. The average density of the composite with a fibre fraction of 60% and a resin fraction of 40% was determined to be 1.561 g/cm³.

Table 4
Density test results at 45°

Specimen	Mass in Air (gr)	Mass in Water (gr)	Water Density (g/cm³)	Specimen Density (g/cm³)
1	0.7725	0.3074	0.97737	1.623
2	0.8345	0.2870	0.97737	1.489
3	0.8712	0.3039	0.97737	1.500
4	0.7595	0.3140	0.97737	1.666
5	0.8208	0.2953	0.97737	1.526
Average	-	-	-	1.561

3.2 Tensile for Materials

In this tensile test, the specimens (Figure 3) were cut to a length in accordance with ASTM D3039 and a width in accordance with ASTM D3039.

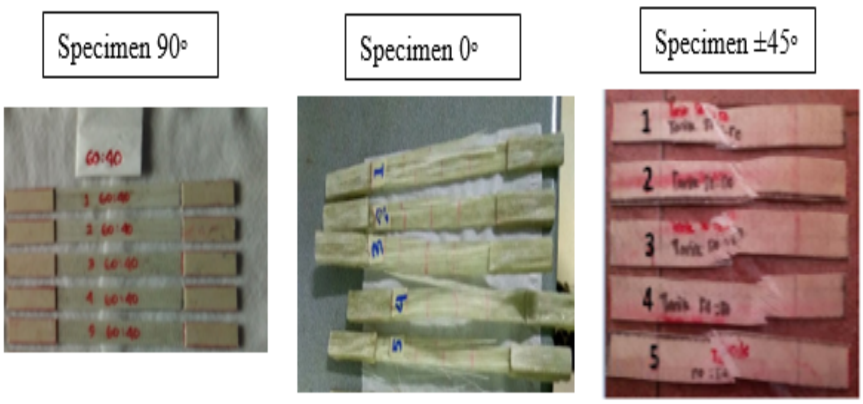


Fig. 3. Tensile test specimen

As presented in Table 5, among the three fibre orientations (0°, 90° and ±45°), the highest Young's modulus is achieved in the 90° fibre orientation with a composition of 60% fibre and 40% resin, reaching 25,255.33 MPa, while the lowest Young's modulus is observed in the ±45° fibre orientation at 4,573.9 MPa. Regarding maximum stress, the ±45° fibre orientation exhibits the highest value at 809.69 MPa, whereas the 0° fibre orientation shows the lowest at 424.08 MPa. Additionally, the maximum load recorded is highest for the 90° fibre orientation, at 10,822.20 N and lowest for the ±45° fibre orientation, at 5,895.4 N.

Table 5
Average test results of volume fraction ratio

Composite Fibre Variation	Maximum Point Stress (MPa)	Maximum Load (N)	Young's Modulus (MPa)
0°	424.08	9721.02	20576.20
90°	641.96	10822.20	25255.33
±45°	80.96	5895.40	4573.90

The average altitude of the unmanned aerial vehicle (UAV) was maintained between 5000 and 1000 feet for testing purposes. At lower altitudes, the wind pressure increases significantly, affecting the mechanical properties of materials. Consequently, tensile strength tests were performed to evaluate and compare the mechanical performance of composite materials with fibre orientations of 0°, 90° and ±45° under varying wind pressures experienced at these altitudes. The wind pressure values, initially measured in PSI, were converted to megapascals (MPa), as detailed in the corresponding Table 6.

Table 6
Altitude and wind pressure strength of unmanned aerial vehicle

No	Altitude (Feet)	Temp (°C)	Pressure (Psi)	Conversion To (MPa)
1	5000	5.1	12.23	0.084323
2	4000	7.1	12.69	0.087494
3	3000	9.1	13.17	0.090804
4	2000	11	13.67	0.094251
5	1000	13	14.17	0.097699

4. Conclusions

This study successfully revealed that the fibre orientation in roving fibre composites with BQTN R157 polyester resin significantly influences their mechanical properties, particularly tensile strength, elastic modulus and material density. The results demonstrated that the 90° fibre orientation exhibited the highest elastic modulus of 25,255.33 MPa, reflecting the material's capacity to withstand elastic deformation. Meanwhile, the ±45° fibre orientation achieved the maximum tensile strength of 80.969 MPa, indicating the potential of this material to endure higher axial loads. Additionally, density testing showed that the 90° fibre orientation had the highest average density of 1.844 g/cm^3, signifying consistent fibre and resin distribution in this configuration. Furthermore, atmospheric pressure analysis at various altitudes revealed that composites with a 90° fibre orientation could withstand air pressure under the operational conditions of unmanned aerial vehicles (UAVs), with a maximum tensile strength of 641.96 MPa, exceeding the encountered air pressures. This indicates that the material not only possesses optimal mechanical strength but is also suitable for UAV applications operating at specific altitudes. The findings of this study contribute significantly to the development of composite materials for UAV applications, particularly in designing lightweight and pressure-resistant structures. This research also opens opportunities for further studies, including the optimization of composite material combinations and testing in more complex operational environments to expand its application in aerospace and aviation technologies.

Acknowledgement
The authors extend their gratitude to Universitas Muhammadiyah Jakarta for providing facilities and resources that significantly contributed to the completion of this study. Special thanks are also directed to our colleagues who offered valuable insights and expertise throughout the research process.

References
[1] Rajoo, Previndran Guinda, Mohamed Thariq Hameed Sultan andrzej Łukaszewicz, Adi Azriff Basri, Ain Umaira Md Shah, Suhas Yeshwant Nayak, Rafa ł Grzejda and Andriy Holovatyy. "The Development of UAV Airframes Made of Natural Fibres: A Review." (2023). https://doi.org/10.20944/preprints202307.0528.v1
[2] Ganesan, Dharmalingam, Arun Prasad Murali, Sachin Salunkhe, Hariprasad Tarigonda and Vishal Naranje. "Effect of microcrystalline cellulose on mechanical properties of flax-jute-epoxy hybrid composite materials using vacuum bagging." *Journal of Reinforced Plastics and Composites* (2024): 07316844241247887. https://doi.org/10.1177/07316844241247887
[3] Setyabudi, Sofyan Arief, Moch Agus Choiron and Anindito Purnowidodo. "Effect of angle orientation lay-up on uniaxial tensile test specimen of Fibre carbon composite manufactured by using resin transfer moulding with

vacuum bagging." In *IOP Conference Series: Materials Science and Engineering*, vol. 494, no. 1, p. 012020. IOP Publishing, 2019. https://doi.org/10.1088/1757-899X/494/1/012020

[4] Dong, Guang-He, Fang-Liang Guo, Zheng Sun, Yuan-Qing Li, Shu-Feng Song, Chao-He Xu, Pei Huang, Cheng Yan, Ning Hu and Shao-Yun Fu. "Short carbon fibre reinforced epoxy-ionic liquid electrolyte enabled structural battery via vacuum bagging process." *Advanced Composites and Hybrid Materials* 5, no. 3 (2022): 1799-1811. https://doi.org/10.1007/s42114-022-00436-z

[5] Isna, Lathifa Rusita, Afid Nugroho, Rezky Agung Pratomo and Redha Akbar Ramadhan. "Properties Comparison of Open Hole and Non-Hole Carbon UD-Lycal Composite with Vacuum Bagging Manufacturing Method." *Jurnal Teknologi Dirgantara* 19, no. 01 (2021): 25-32.

[6] Chumpon, Pawarit, Phattharasaya Rattanawongkun, Nattaya Tawichai, Uraiwan Intatha and Nattakan Soykeabkaew. "Fabrication of all-cellulose composite from cotton fabric via NaOH/Urea solvent using vacuum bagging-assisted process." *Key Engineering Materials* 889 (2021): 9-14. https://doi.org/10.4028/www.scientific.net/KEM.889.9

[7] Nagesh, Athreya, Ola Rashwan and Ma'moun Abu-Ayyad. "Optimization of the Composite Airplane Fuselage for an Optimum Structural Integrity." In *ASME International Mechanical Engineering Congress and Exposition*, vol. 52002, p. V001T03A031. American Society of Mechanical Engineers, 2018. https://doi.org/10.1115/IMECE2018-88215

[8] Armas, Reza Febriano and Susanto Sudiro. "Optimasi pada Welding Station untuk Menekan Waktu tidak Produktif pada Pengelasan Robotik Rangka Tempat Tidur." *Teknobiz: Jurnal Ilmiah Program Studi Magister Teknik Mesin* 11, no. 3 (2021): 151-158. https://doi.org/10.35814/teknobiz.v11i3.2902

[9] Balakumaran, V., Ramasamy Alagirusamy and Dinesh Kalyanasundaram. "Epoxy based sandwich composite using three-dimensional integrally woven fabric as core strengthened with additional carbon face-sheets." *Journal of the Mechanical Behavior of Biomedical Materials* 116 (2021): 104317. https://doi.org/10.1016/j.jmbbm.2021.104317

[10] Rasma, Rasma, Reza Febriano Armas and Agung Riyadi. "Analysis of Fill Switch Failure Leading to Transmission Inability to Shift Speeds in the Haulpak 530M Unit." In *International Conference on Engineering, Applied Sciences and Technology*, vol. 1, no. 1. 2024.

[11] Ramadhan, Anwar Ilmar, Tri Yuni Hendrawati, Efrizon Umar, Alvika Meta Sari and Istianto Budhi Rahardja. "Preparation And Characterization Of Nano-Cellulose Powder From Oil Palm Empty Fruit Bunches As Green Nanofluids." *Nanoscience and Technology: An International Journal* 16, no. 1 (2025). https://doi.org/10.1615/NanoSciTechnolIntJ.2024050024

[12] Sari, Dewi Karmila. "Studi Sifat Mekanik Komposit Serat E-Glass±45-Epoxy Dengan Metode Vacuum Bagging Untuk Aplikasi Pesawat Tanpa Awak." PhD diss., Universitas Airlangga, 2016.

[13] Kartini, Aprilia Tri, Erwhin Irmawan and Ferry Setiawan. "Manufaktur UAV Fixed Wing Menggunakan Material Styrofoam Dengan Metode Lay-Up (Pelapisan) Fibreglass Dan Resin." *Teknika STTKD: Jurnal Teknik, Elektronik, Engine* 10, no. 1 (2024): 44-52. https://doi.org/10.56521/teknika.v10i1.1054

[14] Armas, Reza Febriano, Ari Aryadi and Nugroho Putra Pratama. "Design and Build Special Service Tools for Remove & Install Drive Shaft for Komatsu HD785-7 Dump Truck." *Jurnal E-Komtek (Elektro-Komputer-Teknik)* 8, no. 1 (2024): 199-206.

[15] Ramadhan, Anwar Ilmar, Wan Hamzah Azmi, As Natio Lasman, Efrizon Umar and Korada Viswanatha Sharma. "Heat Transfer Analysis and Friction Factor of Ternary Nanofluids with Twisted Tape Inserts." *Indonesian Journal of Computing, Engineering and Design (IJoCED)* 6, no. 2 (2024): 142-159. https://doi.org/10.35806/ijoced.v6i2.473

[16] Ramadhan, Anwar Ilmar, Kushendarsyah Saptaji, Tri Yuni Hendrawati, Alvika Meta Sari, Efrizon Umar, Azmairit Aziz, Rifqi Putra Semendo, Hanif Rama Yuda Setiawan and Firmansyah Firmansyah. "Investigation of Thermal Conductivity and Dynamics Viscosity of Green Nanofluids (ZrO2-SiO2)." *Jurnal Teknologi* 16, no. 2 (2024): 301-312.

[17] Yusuf, Yusuf, Anwar Ilmar Ramadhan, Efrizon Umar, Rian Fitriana, Firmansyah Firmansyah and Wan Hamzah Azmi. "Efficiency Analysis for Plate Type Heat Exchangers Using Nanofluids in the Primary Cooling System of the TRIGA 2000 Nuclear Reactor with Computational Fluid Dynamics Code." *Journal of Applied Sciences and Advanced Technology* 6, no. 3 (2024): 117-128.

[18] Reddy, RV Saikumar, D. Mohana Krishnudu, P. Rajendra Prasad and P. Venkateshwar Reddy. "Alkali treatment influence on characterization of setaria italic (Foxtail Millet) fibre reinforced polymer composites using vacuum bagging." *Journal of Natural Fibres* 19, no. 5 (2022): 1851-1863. https://doi.org/10.1080/15440478.2020.1788494

[19] Abdalikhwa, Hayder Zaher, Mohsin Abdullah Al-Shammari and Emad Qasem Hussein. "Characterization and buckling investigation of composite materials to be used in the prosthetic pylon manufacturing." In *IOP Conference Series: Materials Science and Engineering*, vol. 1094, no. 1, p. 012170. IOP Publishing, 2021. https://doi.org/10.1088/1757-899X/1094/1/012170

[20] Dalfi, Hussein Kommur, Rand Ayad, Khadhum Shabeeb, Khayale Jan and Roy Conway. "Enhancing the quasi-static strength of prosthetic socket made from composite laminates via hybridisation: experimental and numerical

study." *Journal of Industrial Textiles* 53 (2023): 15280837231178567. https://doi.org/10.1177/15280837231178567
[21] Ahmed, S. and J. Oleiwi. "Tensile and buckling of prosthetic pylon made from hybrid composite materials." *Eng Tech J* 34 (2016): 2642-2653. https://doi.org/10.30684/etj.34.14A.9
[22] Ramadhan, A. I., W. H. Azmi and R. Mamat. "Heat transfer characteristics of car radiator using tri-hybrid nanocoolant." In *IOP Conference Series: Materials Science and Engineering*, vol. 863, no. 1, p. 012054. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/863/1/012054
[23] Azmi, W. H., M. F. Ismail, N. N. M. Zawawi, R. Mamat and S. Safril. "WITHDRAWN: Tribological and residential air conditioning performance using SiO2-TiO2/PVE nanolubricant." (2024). https://doi.org/10.1016/j.ijrefrig.2024.01.002
[24] Azmi, W. H., K. Abdul Hamid, A. I. Ramadhan and A. I. M. Shaiful. "Thermal hydraulic performance for hybrid composition ratio of TiO2–SiO2 nanofluids in a tube with wire coil inserts." *Case Studies in Thermal Engineering* 25 (2021): 100899. https://doi.org/10.1016/j.csite.2021.100899
[25] Hanafi, M. Y., M. F. Ghazali, W. H. Azmi, M. F. M. Yusof and M. A. PiRemli. "Hydroinformatics based technique for leak identification purpose–An experimental analysis." In *IOP Conference Series: Materials Science and Engineering*, vol. 1078, no. 1, p. 012038. IOP Publishing, 2021. https://doi.org/10.1088/1757-899X/1078/1/012038
[26] Ramadhan, Anwar Ilmar, Alvika Meta Sari, Kushendarsyah Saptaji, Istianto Budhi Rahardja, Efrizon Umar, Satrio Yudho Perdana and Wan Hamzah Azmi. "Characterization and Stability of ZrO2-SiO2 Nanofluids from Local Minerals Indonesia as Green Nanofluids to Application Radiator Cooling System." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 111, no. 2 (2023): 126-140. https://doi.org/10.37934/arfmts.111.2.126140
[27] Ismail, Syahriza, Khairil Azwa Khairul, Zainovia Lockman and Zhwan Dilshad Ibrahim Sktani. "Mechanism of Co3O4-TiO2 Nanocomposite Formation with Enhanced Photocatalytic Performance." *Journal of Advanced Research in Micro and Nano Engineering* 23, no. 1 (2024): 49-60. https://doi.org/10.37934/armne.23.1.4960
[28] Haniffah, Nur Akmal, Mohamad Shahrizan Mohd Kamal and Syafawati Hasbi. "Design and fabrication of a simple device for folding towel." *Journal of advanced research in applied sciences and engineering technology* 44, no. 2 (2024). https://doi.org/10.37934/araset.44.2.221233
[29] Hamisa, Abdul Hamid, Wan Hamzah Azmi, Taib Mohd Yusof, Mohd Farid Ismail and Anwar Ilmar Ramadhan. "Rheological Properties of TiO2/POE Nanolubricant for Automotive Air-Conditioning System." *J. Adv. Res. Fluid Mech. Therm. Sci* 90 (2022): 10-22. https://doi.org/10.37934/arfmts.90.1.1022