

Effect of Na₂S treatment and oil palm empty fruit bunch fibre content on the mechanical properties of polyester composites for potential automotive applications

Latiful Fadly*, Sutan Lazrisyah, Dedikarni Panuh

Department of Mechanical Engineering, Universitas Islam Riau

*Corresponding author: m.latifulfadly@student.uir.ac.id

ABSTRACT

Oil palm empty fruit bunch (OPEFB) is an abundant lignocellulosic residue with potential as reinforcement for polymer composites. This study evaluates the effect of OPEFB fibre content and sodium sulfide (Na₂S) treatment on the mechanical behaviour of polyester-based composites for potential automotive applications. OPEFB fibres were treated with 4 wt.% NaOH combined with Na₂S concentrations of 0, 2, 3, 4, and 6%, and composites were prepared at nominal resin:fiber compositions of 100:0, 70:30, and 50:50. Tensile properties were evaluated according to ASTM D638 Type I, while impact behavior was assessed using a pendulum impact test. Increasing Na₂S concentration generally enhanced tensile strength and elastic modulus. The highest tensile strength (12.81 MPa) and elastic modulus (391.62 MPa) were obtained for the 70:30 composite treated with 6% Na₂S. The 50:50 composite also showed improved tensile strength, reaching 12.23 MPa at 6% Na₂S, although its performance remained slightly below that of the 70:30 composition. Elongation at break exhibited a non-monotonic response, indicating a strength-stiffness-ductility trade-off. These findings demonstrate that Na₂S-assisted alkaline treatment can improve the mechanical response of OPEFB/polyester composites; however, further statistical validation, interfacial characterization, and quantitative benchmarking are required before suitability for automotive bumper components can be established.

Keywords: OPEFB fiber; polyester composite; Na₂S treatment; tensile properties; automotive materials

INTRODUCTION

Indonesia is one of the world's major palm-oil-producing countries and consequently generates large quantities of oil palm empty fruit bunch (OPEFB) residue. Because OPEFB contains a substantial lignocellulosic fraction, its utilisation as reinforcement in polymer composites offers a pathway to increase the value of agricultural waste while reducing dependence on fully synthetic reinforcement. Previous studies have shown that natural-fibre-reinforced polymer

composites can provide useful combinations of low density, renewability, and mechanical performance for non-structural engineering applications (Adlie et al., 2018; Maryanti et al., 2011; Rusly et al., 2023).

A major limitation of OPEFB and other natural fibres is the presence of lignin, hemicellulose, waxes, pectin, and surface impurities, which can restrict wetting and reduce interfacial adhesion with hydrophobic polymer matrices. Alkaline treatment with sodium hydroxide (NaOH) is

commonly used to remove part of these non-cellulosic constituents and to increase fibre surface roughness, thereby promoting mechanical interlocking with the matrix. The effectiveness of alkaline treatment depends strongly on chemical concentration and processing conditions, and excessive treatment may damage the fibre structure or reduce ductility (Maryanti et al., 2011; Permana et al., 2024).

Sodium sulfide (Na_2S), when combined with alkaline media, is associated with enhanced lignin removal through reactions analogous to those used in Kraft delignification. A cleaner and rougher fibre surface may improve stress transfer across the fibre-matrix interface and consequently increase tensile strength and stiffness. However, limited information is available on the combined influence of NaOH - Na_2S treatment and OPEFB fibre content on the tensile, elastic, elongation, and impact behaviour of polyester composites. Therefore, this study investigates OPEFB/polyester composites produced at three nominal resin: fibre compositions and treated with 4 wt.% NaOH at different Na_2S concentrations. The objective is to identify the composition and treatment condition that provides the most balanced mechanical performance and to assess its potential for further development toward non-structural automotive applications.

METHOD

The OPEFB fibres were cleaned to remove adhering dirt and impurities, then cut to approximately 1–2 mm.

The fibres were boiled in water for five minutes, rinsed with clean water, and dried before chemical treatment. The purpose of this preliminary cleaning stage was to minimise residual contaminants that could interfere with subsequent alkaline treatment and resin-fibre bonding.

The dried OPEFB fibres were treated using 4 wt.% NaOH combined with Na_2S concentrations of 0, 2, 3, 4, and 6%. The treatment duration was 2 h. After treatment, the fibres were rinsed with distilled water until they reached neutral pH, then dried before composite fabrication. We fabricated composites using the hand lay-up method with polyester resin as the matrix. Three nominal resin: fibre compositions were investigated:

1. 100% polyester resin : 0% OPEFB fibre
2. 70% polyester resin: 30% OPEFB fibre
3. 50% polyester resin: 50% OPEFB fibre

A catalyst was added to the polyester resin before mixing with the fibres to initiate curing. The resin-fibre mixture was placed in silicone-rubber moulds and cured at room temperature. After curing, specimens were removed from the moulds and finished with abrasive paper to obtain uniform dimensions. To ensure reproducibility, the final manuscript should report the resin grade and manufacturer, catalyst type and concentration, mixing procedure, curing time, mould dimensions, fibre orientation, and the basis used to define the stated resin: fibre fractions (mass fraction or volume fraction).

Tensile testing was conducted using a Universal Testing Machine (UTM) according to ASTM D638 Type I to

determine tensile strength, elastic modulus, and elongation at break. Impact testing was conducted using a pendulum impact tester. The final manuscript must verify that the selected impact-test standard is appropriate for the polymer-composite specimen geometry and must report specimen dimensions, notch configuration, pendulum capacity, and test calculation procedure. Report mechanical-property results as mean $\pm$ standard deviation based on replicate specimens; when sufficient replicates are available, use statistical analysis such as one-way or two-way ANOVA to evaluate the effects of fibre content and Na₂S concentration.

RESULT AND DISCUSSION

Tensile Strength

Table 1 presents the tensile strength results.

Table 1. Tensile strength of composites

Resin: fiber composition	NaOH (wt.%)	Na ₂ S (%)	Tensile strength (MPa)
100 : 0	—	—	5.76
70 : 30	4	0	7.52
70 : 30	4	2	8.76
70 : 30	4	3	10.68
70 : 30	4	4	11.49
70 : 30	4	6	12.81
50 : 50	4	0	6.69
50 : 50	4	2	8.18
50 : 50	4	3	9.72
50 : 50	4	4	10.93
50 : 50	4	6	12.23

The tensile results show a clear improvement with increasing Na₂S concentration for both fibre-containing compositions. The neat

polyester specimen showed a tensile strength of approximately 5.76 MPa. For the 70:30 resin-fibre composite, tensile strength increased from 7.52 MPa without Na₂S to 12.81 MPa at 6% Na₂S, corresponding to an increase of approximately 70%. The 50:50 composite exhibited a similar trend, increasing from 6.69 MPa to 12.23 MPa over the same Na₂S range. These results suggest that Na₂S-assisted alkaline treatment improves load transfer between OPEFB fibres and the polyester matrix. A plausible mechanism is partial removal of lignin and other surface constituents, which may expose cellulose-rich regions and increase surface roughness, thereby improving mechanical interlocking and interfacial adhesion. The slightly higher tensile strength of the 70:30 composite compared with the 50:50 composite indicates that increasing fibre loading does not necessarily improve strength. At high fibre content, insufficient resin wetting, fibre agglomeration, and void formation may limit stress transfer. This interpretation should be confirmed by fracture-surface microscopy and/or void-content measurements rather than being treated as direct evidence from the present tensile data alone.

Elastic Modulus

Table 2 presents the elastic modulus results.

Table 2. Elastic Modulus of composites

Resin: fibre composition	NaOH (wt.%)	Na ₂ S (%)	Elastic modulus (MPa)
100 : 0	—	—	164.87
70: 30	4	0	234.18
70: 30	4	2	232.64
70: 30	4	3	273.04
70: 30	4	4	374.88
70: 30	4	6	391.62
50: 50	4	0	192.16
50: 50	4	2	211.16
50: 50	4	3	301.65
50: 50	4	4	334.15
50: 50	4	6	385.97

The elastic modulus increased markedly after Na₂S treatment. For the 70:30 composite, the modulus increased from 234.18 MPa at 0% Na₂S to 391.62 MPa at 6% Na₂S, which was the highest stiffness recorded in this study. The 50:50 composite increased from 192.16 MPa to 385.97 MPa. This increase in modulus is consistent with stronger constraint of matrix deformation when interfacial bonding improves. Removal of part of the lignin and hemicellulose may also increase the relative contribution of the stiffer cellulose-rich fiber structure. Nevertheless, the manuscript should specify the strain interval or analysis method used to calculate the elastic modulus from the stress-strain curves and report replicate variability before claiming statistical significance.

Elongation at Break

The Elongation at Break results are presented in Table 3.

Table 3. Elongation at Break of composites

Resin: fibre composition	NaOH (wt.%)	Na ₂ S (%)	Elongation at break (%)
100 : 0	—	—	13.94
70: 30	4	0	8.26
70: 30	4	2	9.66
70: 30	4	3	9.92
70: 30	4	4	6.49
70: 30	4	6	8.11
50: 50	4	0	10.39
50: 50	4	2	9.07
50: 50	4	3	6.82
50: 50	4	4	9.46
50: 50	4	6	8.83

Elongation at break exhibited a non-monotonic response to Na₂S treatment. For the 70:30 composite, elongation increased from 8.26% at 0% Na₂S to 9.92% at 3% Na₂S, decreased to 6.49% at 4% Na₂S, and then increased to 8.11% at 6% Na₂S.

The 50:50 composite varied between 6.82% and 10.39%. This behaviour indicates a strength-stiffness-ductility trade-off rather than a uniform improvement in all properties. Improved interfacial bonding can facilitate stress transfer and increase strength and stiffness, while simultaneously restricting local deformation and fibre pull-out, thereby reducing ductility under some treatment conditions. Interpret the fluctuations alongside standard deviations and fracture-surface observations to distinguish systematic treatment effects from experimental scatter.

Impact Strength

Impact performance is an important consideration for potential

automotive applications because the material must dissipate energy during rapid loading.

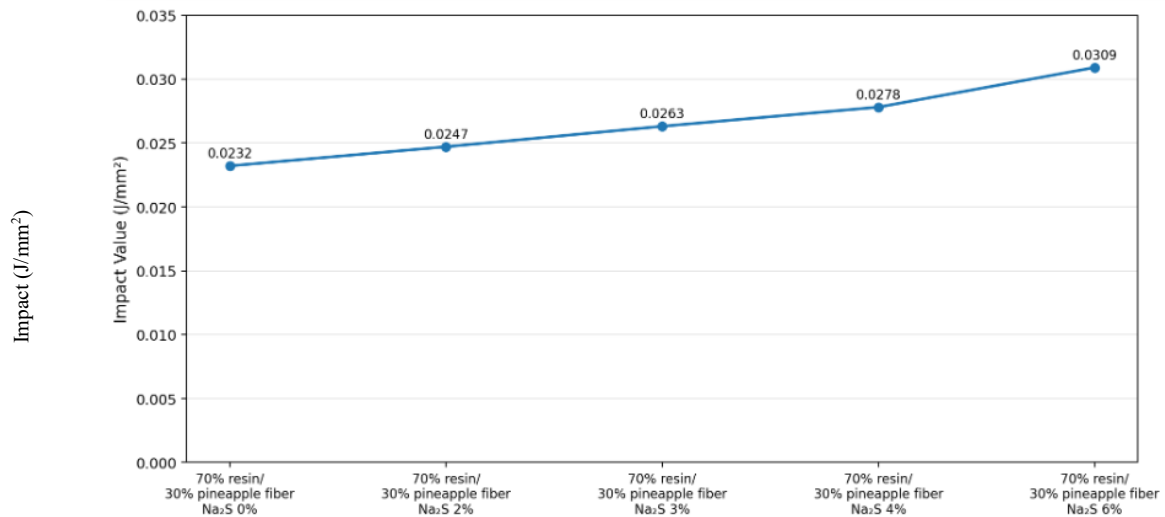


Figure 1. Impact-test results for the 70% resin: 30% OPEFB fibre composite.

The manuscript includes impact-test figures, but it does not report the numerical impact values for each

Na₂S concentration and resin: fibre composition in a complete table.

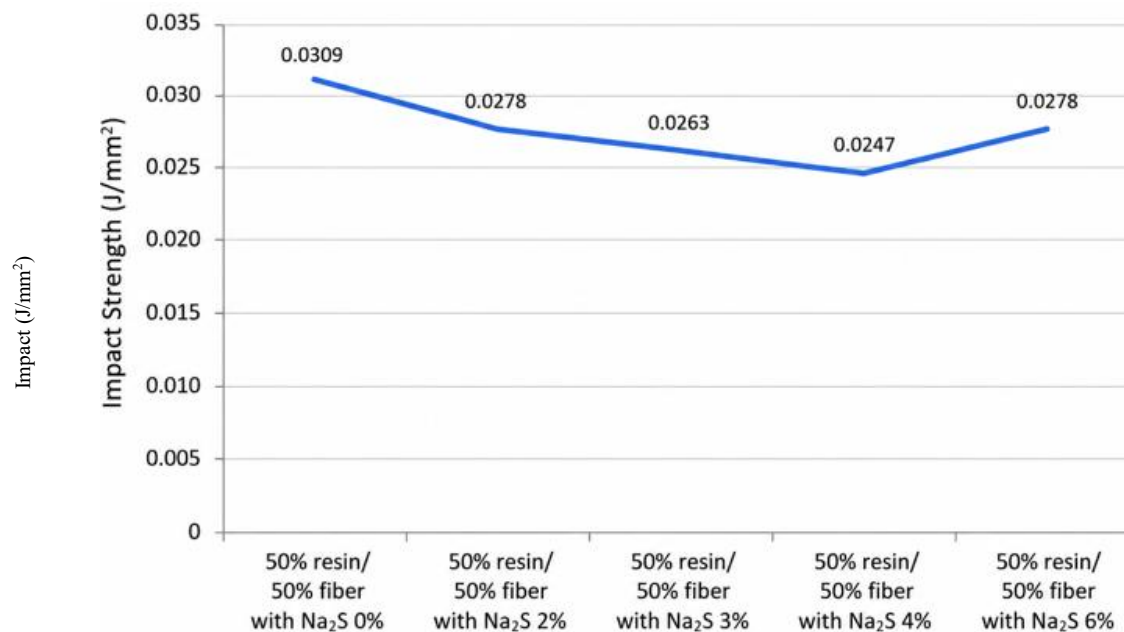


Figure 2. Impact-test results for the 50% resin: 50% OPEFB fibre composite.

Therefore, a quantitative conclusion regarding the optimum impact condition cannot yet be verified. The revised manuscript should report the impact strength or impact energy for each composition as mean $\pm$ standard deviation and quantitatively compare the untreated and treated specimens. Mechanistically, OPEFB fibres may contribute to energy absorption through crack deflection, crack bridging, fibre debonding, and fibre pull-out; however, confirmation of these mechanisms requires fracture-surface evidence such as SEM images. Describe the condition identified as optimum only after providing complete numerical data and statistical variability.

CONCLUSION

This study evaluated the influence of OPEFB fibre content and Na₂S-assisted alkaline treatment on the mechanical behaviour of polyester composites. Based on the available experimental data, the following conclusions can be drawn:

1. Na₂S-assisted treatment produced a consistent increase in tensile strength and, in general, elastic modulus for both the 70:30 and 50:50 resin-fibre composites. After replication, establish statistical significance and report an appropriate statistical test.
2. The highest tensile strength (12.81 MPa) and elastic modulus (391.62 MPa) were obtained for the 70% polyester resin: 30% OPEFB fibre composite treated with 6% Na₂S. The 50:50 composite treated with 6% Na₂S reached a tensile strength of 12.23 MPa and an elastic modulus of 385.97 MPa.

3. Elongation at break showed a non-monotonic response to Na₂S concentration, indicating that improved strength and stiffness were accompanied by changes in ductility. Therefore, evaluate treatment effectiveness by balancing tensile strength, stiffness, elongation, and impact resistance rather than relying on a single property.

4. The 70:30 composite slightly outperformed the 50:50 composite in tensile strength and modulus at the highest Na₂S concentration. This may be related to improved resin wetting and lower defect content at the lower fibre loading, but morphological or void-content characterisation is required to confirm this mechanism.

5. The results demonstrate the potential of Na₂S-treated OPEFB/polyester composites for further development as lightweight, renewable-material-based components.

However, the present data alone cannot establish suitability for automotive bumper applications. Before making an application-level claim, complete impact data, statistical validation, interfacial characterisation, and quantitative comparison with relevant automotive materials and performance requirements are recommended.

REFERENCES

- Adlie, T. A., Arif, Z., Amir, F., Rizal, S., Ali, N., & Thalib, S. (2018). *PENGARUH BEBAN TARIK TERHADAP VARIASI UKURAN SERAT TANDAN KOSONG KELAPA SAWIT KOMPOSIT POLYMERIC FOAM*.

- Andriyanto, F., & Fuadi, A. M. (2024). *PENGARUH WAKTU DAN PELEPASAN PECTIN TERHADAP BILANGAN KAPPA PADA PROSES PEMBUATAN PULP DARI AMPAS TEBU*. 4(1). <https://doi.org/10.46964/jimsi.v4i1.1002>
- Arsalan, H., Subekti, D., & Firmansyah, H. I. (2024). *Pengaruh Panjang Serat terhadap Kekuatan Tarik Fiber Metal Laminate Composite*. 5.
- Aulia, W. D., Permana, A. T., Dimawarnita, F., Aulia, W. D., Permana, A. T., Dimawarnita, F., & Faramitha, Y. (2024). *DELIGNIFIKASI TANDAN KOSONG KELAPA SAWIT (TKKS) DENGAN NaOH TERHADAP KUALITAS PUPUK ORGANIK CAIR DELIGNIFICATION OF EMPTY PALM OIL BUNCHES WITH NaOH ON THE QUALITY OF LIQUID ORGANIC FERTILIZER*. 34(1), 47–54.
- Maryanti, B., Sonief, A. A., & Wahyudi, S. (2011). Pengaruh alkalisasi komposit serat kelapa-poliester terhadap kekuatan tarik. *Rekayasa Mesin*, 2(2), 123–129. [http://download.garuda.kemdikbud.go.id/article.php?article=256322&val=6938&title=Pengaruh Alkalisasi Komposit Serat Kelapa-Poliester Terhadap Kekuatan Tarik](http://download.garuda.kemdikbud.go.id/article.php?article=256322&val=6938&title=Pengaruh%20Alkalisasi%20Komposit%20Serat%20Kelapa-Poliester%20Terhadap%20Kekuatan%20Tarik)
- Mesin, D. T., Teknik, F., & Andalas, U. (2025). *SIFAT MEKANIK KOMPOSIT POLYSTER-MMA DARI SIFAT MEKANIK KOMPOSIT POLYSTER-MMA DARI*.
- Permana, H. A., Delvitasari, F., Hartari, W. R., & Maryanti, M. (2024). Pengaruh Konsentrasi NaOH dan Suhu Delignifikasi pada Kandungan Lignoselulosa Tandan Kosong Kelapa Sawit. *Jurnal Agro Industri Perkebunan*, 12(1), 51–58. <https://doi.org/10.25181/jaip.v12i1.2729>
- Pratiwi, D., & Lubis, R. (2023). *AGRO FABRICA Jurnal Teknik Pengolahan Hasil Perkebunan Kelapa Sawit dan Karet Available online* <https://www.ejurnal.itsi.ac.id/index.php/JAF> *ISOLASI DAN KARAKTERISASI PULP TANDAN KOSONG KELAPA SAWIT ISOLATION AND CHARACTERIZATION ANALYSIS OF OIL PALM EMPTY*. 5(1).
- Rahman Mohammad, A., Muhktar, M., & Bahri, S. (2024). Analisis Hemiselulosa, Selulosa Dan Lignin Eceng Gondok (Eichhornia crassipes) Yang Difermentasi Dengan Berbagai Starter Berbeda. *Jambura Journal of Tropical Livestock Science (JJTLS)*, 2(2), 51–61.
- Rusly, M., Sulistyowati, R., & Toruan, P. L. (2023). Analisis uji tarik komposit serat batang kelakai dengan variasi katalis untuk pembuatan material bumper mobil. 9(1), 43–48.