Performance Evaluation of Calcium Alkali Treated Oil Palm/Pineapple Fibre/Bio Phenolic Composites

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Abstract

The utilisation of Oil Palm Fibre (OPF) and Pineapple Leaf Fibres (PALF) as reinforcement materials for bio phenolic composites is growing in popularity, particularly in automotive lightweight applications. The major purpose of this current study is to investigate the influence of alkali ($Ca(OH)_2$ treatment on pure and hybrid composites. The effects of enhancements in chemical interactions were evaluated by the Fourier Transform Infrared Spectrometer (FTIR). Dynamic Mechanical Analysis (DMA) and Thermogravimetric Analysis (TGA) performance of untreated reinforcements (OPF and PALF) and treated (OPF/OPF) composites at superior temperature and noted sufficient interfacial bonding contributing towards the improvements in thermal stability. From DMA results, the storage modulus improved with treated composites while the damping factor was reduced. Furthermore, the treated hybrid composites exhibited significant improvements in thermal stability compared to untreated fibre composites. The results presented that alkali calcium hydroxide ($Ca(OH_2)$:T) incorporation in hybrid composites (OPF/PALF) results in increased tensile strength and modulus among all composites. Similarly, the alkali-treated ($Ca (OH)_2$) treated pure composite (T/50%PALF), and hybrid composites (T/1OPF.1PALF) exhibited better flexural strength as compared with other composites. In contrast, the T/50% PALF showed higher flexural stress of 78.2MPa while the flexural modulus was recorded at 6503 MPa. It can be proposed from the findings of this study that the alkali treatment (5%$Ca(OH)_2$) can be utilised to improve the strength and efficiency of agriculture biomass to be used as reinforcements in composites. Additionally, the hybridisation of bio-fibre composites has the potential as a novel variety of biodegradable and sustainable composites appropriate for several industrial and engineering applications.

Keywords**:** Hybrid fibre composites; Alkali treatments, Surface modifications, Mechanical properties; Thermal stability.

1. Introduction

In recent years, composites reinforced with renewable materials have drawn growing attention from various industrial sectors [1,2]. Natural plant fibres such as kenaf, hemp, sisal, pineapple leaf, and oil palm fibres are the highly demanding reinforcements used in composites compared to synthetic fibres such as carbon and glass due to their attractive attributes such as low-cost, low density, moderate specific strength, recyclability, biodegradability [3-6]. However, natural plant fibres are susceptible to moisture absorption. Therefore, properties like mechanical and thermal are not comparable to the properties of synthetic-fibre reinforced composites. This is one of the drawbacks of natural fibres reinforced composites. Therefore, scientific researchers have been exploring using the hybrid approach onto natural fibre composites to comply with both environmental and criteria for an important performance. Besides, the understanding of hybridisation of natural fibres with either natural or synthetic fibres presents an opportunity for improving the overall mechanical performances of hybrid composites when they are exposed to various service conditions.

Furthermore, the significant feature of these developed hybrid composites is attributed to their temperature-dependent characteristics due to their standard frequencies and elastic moduli. Thus, the preferred characteristic can be achieved by regulating the temperature [7,8]. Furthermore, natural fibres can improve the composite's interfacial quality and perform an essential function in improving the mechanical characteristics of polymer composites [9]. Therefore, it is essential to perform chemical and physical treatments on natural fibres to enhance surface bonds and achieve outstanding mechanical and thermal properties [9].

Currently, alkaline [10], silane, acetylation, and phenolic treatments are the most frequently utilised techniques for modifying the surface properties of natural fibres. However, among these polymers, epoxy resin has been used to fabricate sustainable composites reinforced with natural fibres that create composite material components with appropriate mechanical, thermal and physical properties [11]. This is due to many attractive attributes of an epoxy matrix that exhibits good chemical and thermal resistance, dimensional stability, high tensile strength, and modulus [12]. Therefore, choosing an appropriate matrix and fabrication method for a composite is essential to achieve desired yields with great features. Furthermore, epoxy composites reinforced with various natural fibres can be fabricated using a simple compression moulding method to achieve high-quality composite laminates compared to other manufacturing processes [12].

Bichang'a et al. [13] assessed the impact of alkali treatment on the mechanical properties of a woven Sisal Fabric (SF) reinforced with bio phenolic matrix composite made from a 40% mass fraction of fibre. They concluded that the chemical treatment of SF with 4% solution (w/v) for NaOH used for an hour at room temperature enhanced the mechanical properties of the corresponding composite. Furthermore, Samuel et al. [14] revealed that the mechanical characteristics of ukam fibre and SF strengthened bio phenolic matrix were significantly impacted by fibres alkali treatment.

The previous findings have stated that the utilisation of different alkali treatment concentrations (3 wt.%, 6 wt.% and 9 wt.% [15] has improved fibre surface morphologies. It was observed that 6 wt.% of NaOH treatment provided the optimal concentration for cleaning the surface for fibre, enhancing tensile properties. An investigation carried out by Mutasher et al. [16] showed that alkali treatment increased the bonding between biophenolic matrix and natural fibre and contributed to improved tensile and flexural properties for an epoxy composite reinforced with treated kenaf fibre [16]. Nayak and Mohanty [17] studied the impact of alkali treatment on the thermal and mechanical properties and the water absorption behaviour of areca sheath fibres. They found that the treated fibre composites improved the thermal and mechanical properties compared to untreated fibre composites. Biocomposites obtained from natural fibre and biopolymer are expected beyond eco-friendly and such composites are characterised as green composites [18]. Besides, the natural fibre sources are abundant available around world to fabricate green biocomposites, which is user friendly and consume less energy thus leaving behind nearly without a carbon footprint. Amongst natural fibres, OPF and PALF fibres are abundantly available and consider as a promising reinforcement for several polymer materials accordingly to mechanical properties.

As far as two types of fibres (OPF and PALF) reinforced biphenolic resin is involved, authors believe that no reported works in the literature covering the effects of calcium hydroxide solution (5%) treatment with the hybridisation on significant natural fibres (OPF and PALF) and reinforced with Biophenolic Resin (BPHR). The novel strategy of this study was followed by incorporating the alkali treated ($Ca(OH)_2$ fibres (OPF and PALF) to improve the interfacial adhesion with a large selection of BPHR matrix, which was evaluated by using several parameters such as chemical, thermal, and mechanical characterisations.

2. Experimental Section

2.1 Materials

Biophenolic based resin (Grade: PH-4055) used was provided by Chemovate Girinagar, Bangalore, India. Pineapple leaf fibres (PALF) type (Ananas comosus) were secured from Tamil Nadu, India, with a typical density of 1.07 $g/cm^{3,}$ while Oil palm fibre (OPF), which utilised in this study, was provided by the Malaysian Palm Oil Board. All applied fibres were collected without any further surface treatment. The physical and mechanical characterisations of PALF and OPF were expressed in former works in detail [19-23]. On the other hand, the chemical compositions of OPF and PALF consist of etc. The chemical composition of OPF with a high cellulose ratio (43-66%) make it more toughness and suitable for biocomposite applications. While the hemicellulose content is about 29% and lignin content is in the range of 13%–25% [18, 24]. On the other hand, PALF fibre has high cellulose formation (70–82%), making it further attractive as a strengthening component of composite materials. The other chemical components of PALF are lignin (5–12%) and ash (1.1%). The low lignin content enhances another benefit for selecting PALF in composite manufacturing [25].

2.2. Treatment of Fibres

OPF and PALF fibres were immersed into purified water, then mixed with an alkaline ($Ca(OH)_2$) solution giving a fixed ratio of (5% wt.) for 3 h. Next, the fibres were cleaned thoroughly regularly by water until pH values became neutralised. After that, the fibres were dried up to 80 °C for 48 h, using a vacuum oven. The chemical concentration and time choice for the treatment of soaking fibre were modified based on a method approved by prior findings [26]. Fig. 1 illustrates the proposed schematic steps of treatments for two fibres used in this study.

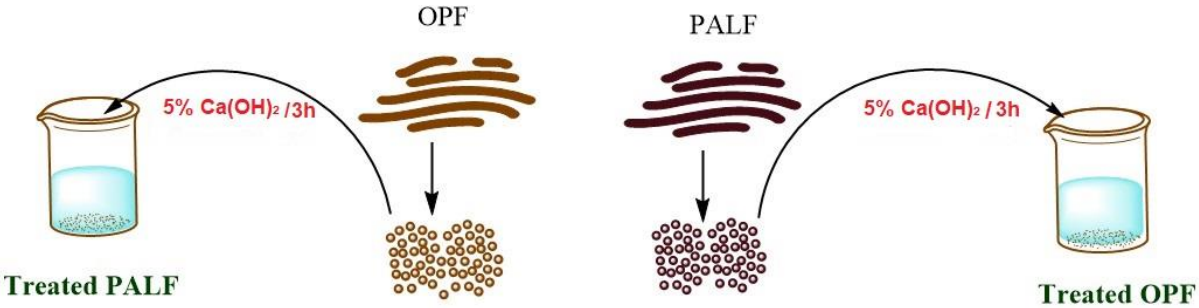

Fig. 1. Schematic illustration of a treated modification of OPF and PALF.

2.3. Composites Preparation

Untreated and treated OPF and PALF fibres are utilised as reinforcing natural fillers to produce bio phenolic composites. Approximately (1-0.8 mm) from untreated and treated fibres were grounded, utilising a grinding system; fibres remained at the storage moisture content (6%–8%). A stainless-steel mould plate within the dimensions of 15 × 15 × 3 mm^3) was utilised to fabricate the untreated and treated fibre composites. The plate was positioned into a hot hydraulic pressure at the temperature of 160 °C. Then, the specimens were removed from the stainless-steel mould after 8 min of compaction. After that, stored at room temperature for cooling, and samples were cut in appropriate sizes from the composite laminates for evaluation.

Fig. 2 shows a schematic illustration of the synthesis of treated fibre-bio-phenolic matrix composites.

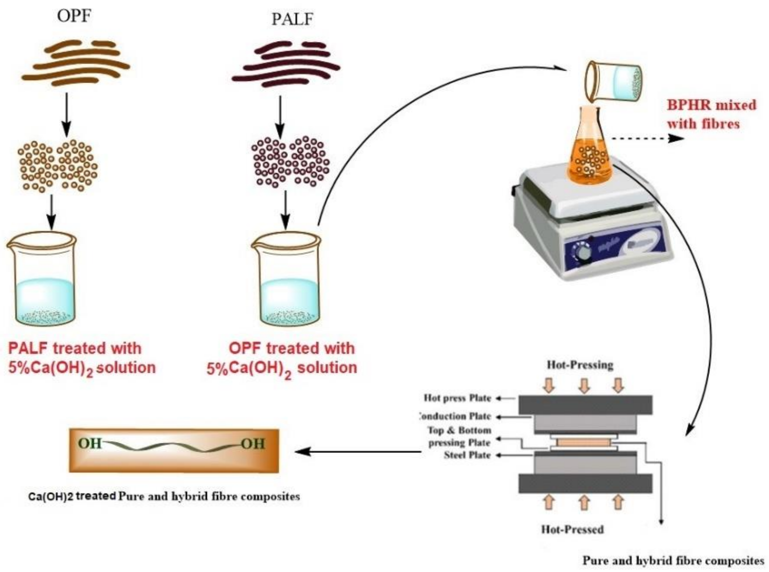

Fig. 2. Schematic illustration of the synthesis of treated fibre-bio-phenolic matrix composites.

3. Characterisations

3.1. FTIR Spectroscopic Analysis

The variations in functional groups of OPF and PALF fibres reinforced bio-phenolic matrix were studied by applying FTIR, class (Instrument: Thermo Scientific Nicolet 6700 with Attenuated Total Reflectance (ATR)) technique. The wavelength selection of the FTIR spectrum was 4000 cm^{-1} to 400 cm^{-1}.

3.2. Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analysis (DMA) tests were carried out in accordance with the ASTM-D 4065-01 standard as a function of temperature. The samples with dimensions (60 L× 12.5 W× 3 mm^3 T) were utilised to estimate the viscoelastic performance of all fibre composites. The DMA tests were performed using a Q800 DMA; TA instruments with the three-point bending mode, and the range of temperature was between 30°C to 150°C at a heating rate of 5°C/min.

3.3. Thermo-Gravimetric Analysis (TGA)

The thermal decomposition of untreated and treated fibre composites was characterised using a thermogravimetric analyser (TGA Q500 TA Instrument, USA). The experiments were performed with a heating rate of 20℃/min from room temperature to 600℃ exposed to an N_2 atmosphere.

3.4. Mechanical Characterisations

The tensile stress-strain behaviours were determined to calculate the tensile strength and young's modulus. The tensile experiments were performed based on the ASTM D3039 by applying the Universal Testing Machine (UTM) model (a 5 kN Blue hill- INSTRON) at a 2 mm/min cross-head speed. All specimens were positioned for preparation at a temperature of 22 °C while the relative humidity was 50%. Five specimens were analysed from each sort of composite, and average values were reported. On the other hand, the flexural specimens with dimensions of length, width, and thickness (280 mm x 52 mm x10 mm^3) were formed and tested in accordance with the standard of ASTM D790, utilising a Bluehill Instron (30 kN loading)-5567 universal testing unit. The velocity of the cross-head was normalised at 2.0 mm/min. Hence, the cross-head motion for this research finding is 4.26 mm/min. The test was achieved at monitored room temperature 23℃ and relative humidity (55%). Five specimens were examined from each type for flexural experiments. For impact characterisation, the dimensions of composites were 70×15×8 mm^3, which were analysed by utilising (Instron Impact machine: CEAST 9050). The conditions and measurements of the experiments were carried out based on the ASTM D256-10e1. Furthermore, the temperature and humidity were verified at 22°C and 50%. Five specimens for each assessment were used, and average values were reported.

4. Results and Discussion

4.1. FTIR Analysis

The spectra of FTIR for all fibre composites studied are displayed in Figs 3 and 4. From Figs 3 and 4, there is a strong wide-ranging band in the spectra group of 3400 cm^{-1}, which is attributed to various stretching for (O–H) approaches, while the other two groups are observed in 2850 and 2920 cm^{-1}, associated asymmetric and stretching for symmetric groups; methyl ($-CH_3$)and methylene ($-CH_2$) existing in the fibre components spectra, but most remarkably in the cellulose spectra [27, 28]. The bands at 1595, 1510 and 1270 cm^{-1} appeared in the fingerprint region due to the stretching of groups showing in lignin composition (C=C, C–O) [29]. On the other hand, the deformation of the stretching vibration for bands (C–H, C–O) appeared in the spectra peaks (1460, 1425, 1335, 1220 and 1110 cm^{-1}), which are attributed to lignin and carbohydrates [29]. From Fig. 3, the treated composites exhibited higher intensity than those of untreated composites. However, the treated hybrid composites showed the greatest absorbance intensity among all other samples. The region of broad peaks between (3200–3550 cm^{-1}) was due to the strong stretching bands (O–H), which showed in all composites. The carbonyl group (C=O) in the region (1675 cm^{-1}) exhibited a stretching vibration of ester and carboxylic groups for hemicellulose, which showed in both untreated and treated pure and hybrid fibre composites. However, the (C=O) group exhibited higher absorbance peaks for treated fibre composites than treated fibre composites, especially for treated hybrid fibre composites compared to pure fibre composites due to the effective elimination of the hemicellulose from treated strengthened composites during the treatment of alkali. From these findings, it can be assumed that the alkali $Ca(OH)_2$ had effectively eliminated the hemicellulose and lignin from fibre composites strengthened biophenolic composite that the alkali treatment had effectively eliminated [30]. John and Anandjiwala reviewed the developments in chemical modification and characterisation of natural fibre–

polymeric composites, and they concluded that alkali treatment is the most common and efficient method of chemical modification to treat natural fibres [31].

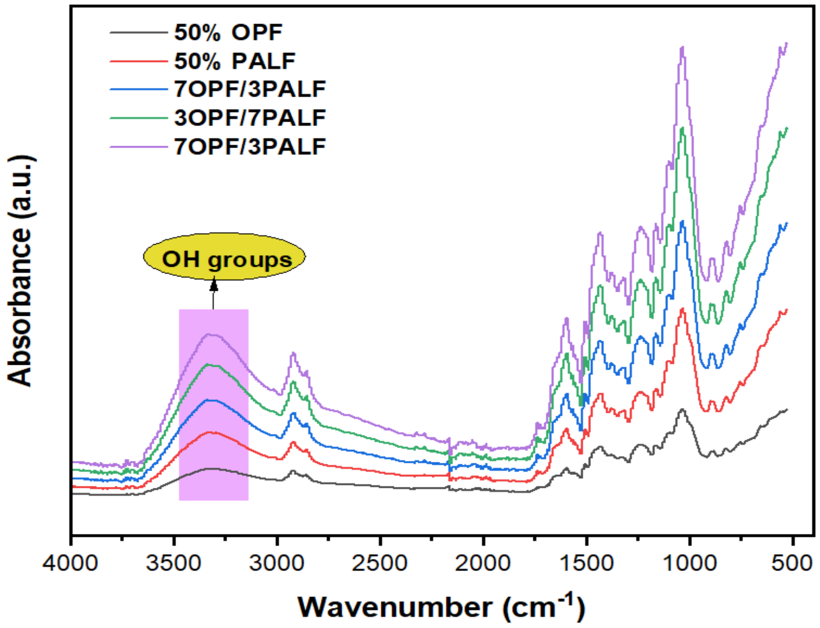

Fig. 3. FTIR spectra of the untreated pure and hybrid fibre composites

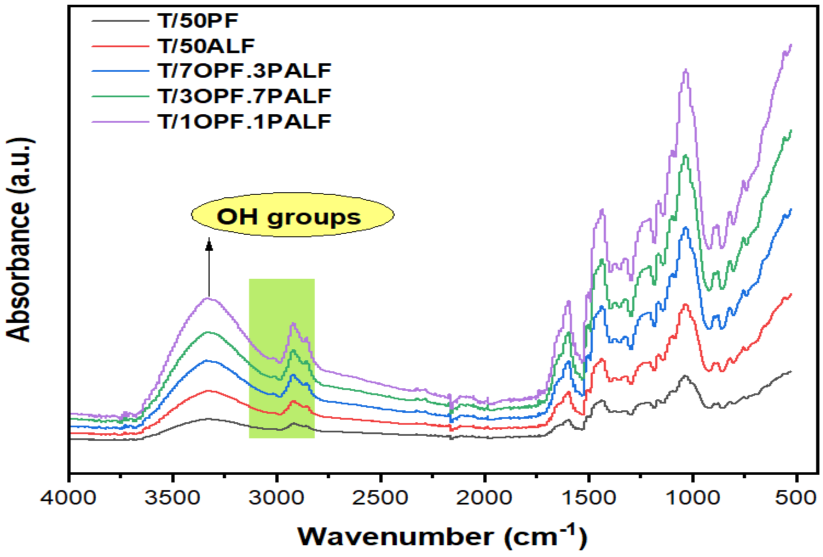

Fig. 4. FTIR spectra of the Treated hybrid naural fibre composites

4.2. DMA Characterisations

Storage modulus taken from the DMA reveals the materials' stiffness [32]. It can be explained that the materials absorb the highest quantity of energy during each oscillation cycle. The storage modulus changes with a temperature of untreated and treated pure and hybrid fibre composites at a frequency (1 Hz) is displayed in Figs. 5 and 6. The improvement in storage modulus was obtained as a result of the incorporation of hybrid fibres filled PHR composites. Treated hybrid fibre composite (T/1OPF.1PALF) exhibited higher storage modulus due to the greatest interfacial bonding between the biophenolic resin matrix and natural fibres, thus providing constant stress transfer. At all events, the storage moduli for the composites were realised to reduce as temperature increased. This can result from the lowering in the toughness of fibres at higher temperatures [33, 34]. In the transition area, it was shown that all composites had values with a stable decline in terms of storage moduli with an increase in temperature attributable to the composites softening as temperature increased.

On the other hand, the greatest value improved in the rubbery area for hybrid fibre composites compared to those untreated hybrid composites. This reality reveals that treated hybrid composites are stiffer composite materials than all untreated corresponded hybrid composites. On the other side, Figs. 5 and 6 exhibited the damping variation with a temperature for hybrid composites at the frequency of (1 Hz). The damping factor term (Tan δ) illustrates the viscoelasticity of material that shows a relaxation method. The damping factor represents the loss and storage modulus ratio, which relies on the linkage between matrix and fibres [35,36]. The strong adhesion between the polymer matrix and the fibres results in composite materials with low damping.

On the other hand, the great interfacial bonding between fibres and polymer matrix can inhibit the flexibility of the polymeric chains and reduce damping and rise in load-bearing capacity.

Consequently, the treated hybrid composite exhibited the lowest damping peaks than other composites, as shown in Fig. 6.

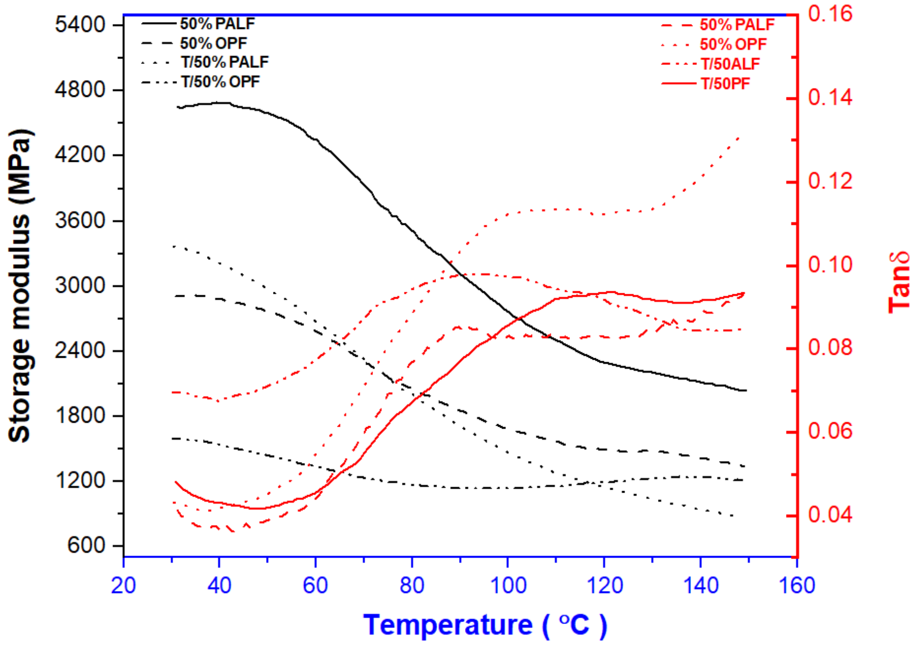

Fig. 5. Storage modulus and damping (Tan δ) variation with temperature of pure composites.

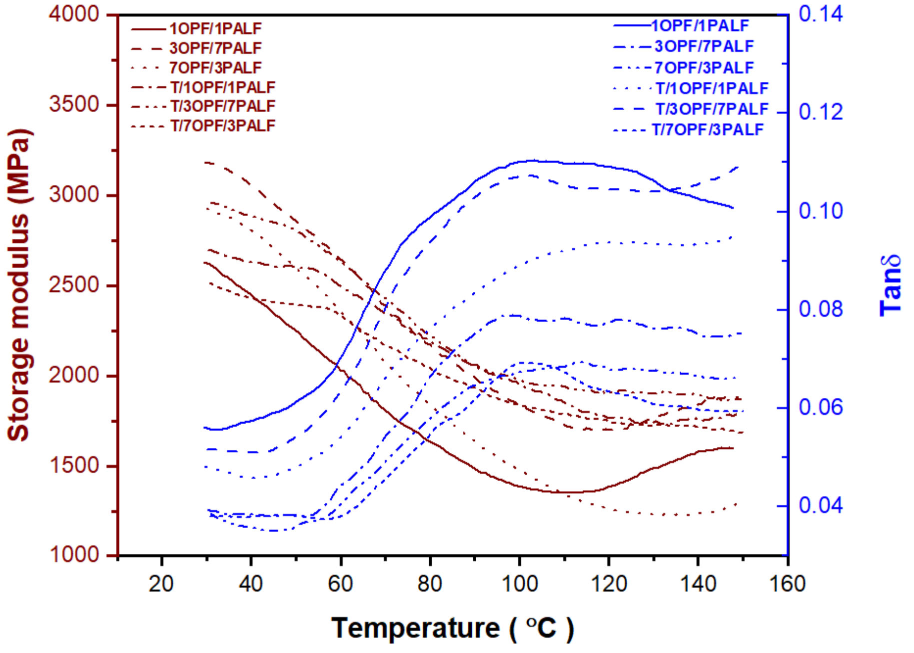

Fig. 6. Storage modulus and damping (Tan δ) variation with temperature of hybrid composites.

The existence of bonding agents produces further crosslinks, and alkali treatment on fibres indicates reinforcing these crosslinks. Therefore, molecular motion beside the macromolecular rubber chain was cruelly hindered, leading to low damping qualities. Similar findings were reported by Jacob et al. [37] showed that the storage modulus (E′) of OPF-Sisal Fiber (SF) hybrid composites improved when chemical treatments were performed on fibres. Higher amounts of loss modulus (E″) were displayed in SF composites with 4%NaOH. They concluded that the alkali treatment of fibre composites showed better interfacial adhesion and led to more crosslinks within the rubber matrix/fibre network and thus, the É̋ increased. The loss modulus increased from 634 to 655 MPa when fibres were treated with 0.5% NaOH. On the other hand, the loss modulus further increased to 801MPa when fibres were treated with 4% NaOH. However, treated fibre composites exhibited low mechanical damping parameters (Tan δ).

4.3. Thermal Characterisations

The thermal decomposition behaviour for untreated and treated pure and hybrid fibre composites was investigated by TGA and the derivative of thermogravimetric (DTG). The results from TGA and DTG are shown in Figs. 7-10 and summarised in Table 1. From TGA curves, the mass loss was observed in two regions for all fibre composites. The first phase was 260°C~400°C, relating to pure and hybrid fibres' thermal decomposition mass loss. The second phase range (400°C~500°C) corresponds to the heat decomposition of fibre types-Biophenolic composites. The onset decomposition temperature (T_{onset}) of treated fibres composites was observed above 300°C while the untreated fibre composites displayed below 300°C. However, from Figs. 7 and 8, it can be shown that no mass loss before 200°C, which may be due to the moisture in the composites nearly fully evaporating. The highest T_{onset} value was observed in the treated pure composite sample (T/50%PALF) compared to other composites, as indicated in Table 1. The onset decomposition temperature for treated hybrid (T/1OPF/1PALF, T/3OPF.7PALF, and T/7OPF.3PALF) composites was 317.94℃ 335.72℃, and 331.80℃, respectively, T_{onset} values were 290.39℃, 286.92℃, and 294.43℃ for untreated hybrid (1OPF/1PALF, 3OPF.7PALF, and 7OPF.3PALF) composites.

The maximum decomposition temperature (T_{max}) values for treated composites were significantly increased compared with untreated composites. However, the T_{max} value for (T/%50PALF) composite exhibited 376.28℃ among all composites untreated and treated pure composites. The T_{max} values were 361.30℃, 374.8℃, and 376.25℃ for hybrid fibre composite: T/1OPF.1PALF, T/3OPF/7PALF, and T/7OPF.3PALF, respectively. The expansion in composite materials' thermal stability is due to the char produced from the decomposition of OPF/PALF hybrid composites, which absorb large amounts of heat and present a barrier to the volatile decomposition yields of the PHR matrix. The residue weights of the alkali-treated fibres were found to be the highest values compared to other composites, as shown in Table 1. Thermal degradation of treated OPF revealed that initial degradation temperature was higher for alkali-treated fibres (350 °C), whereas untreated and acetylated fibres degraded at 325 °C and silane treatment increased the degradation temperature to 365 °C [38].

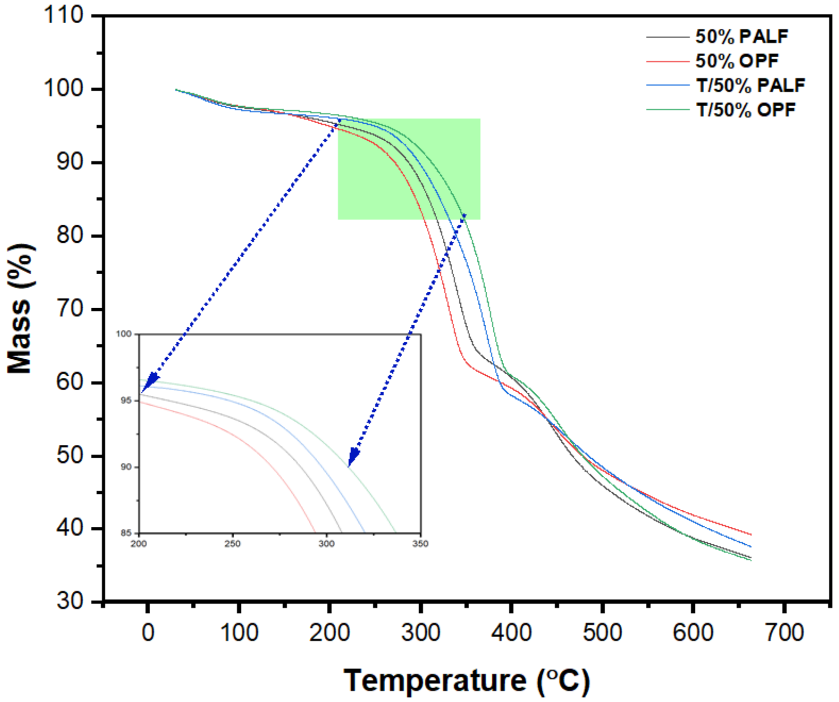

Fig. 7. TGA curves of the untreated and treated pure composites.

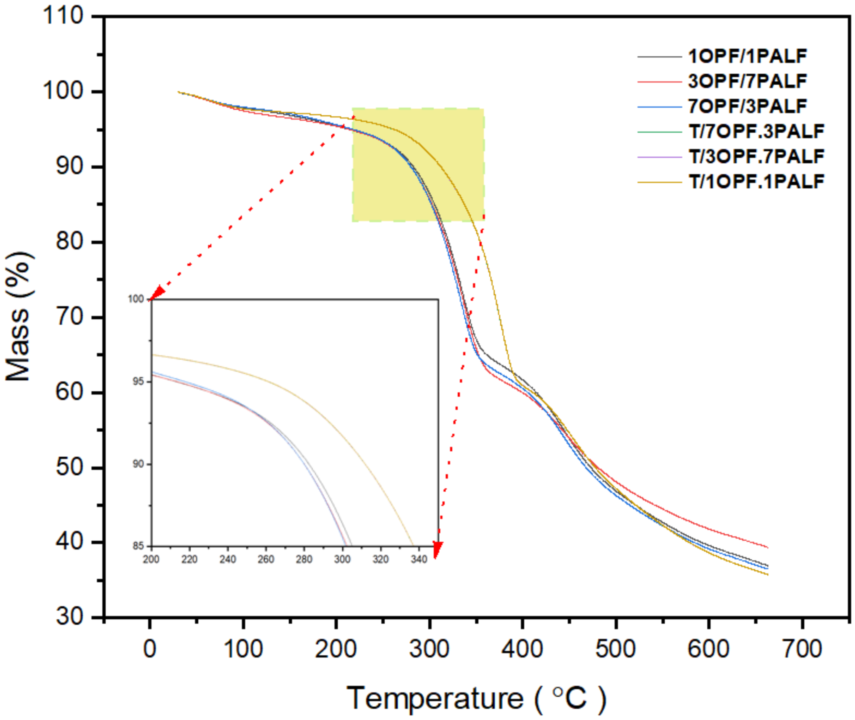

Fig. 8. TGA curves of the untreated and treated hybrid composites.

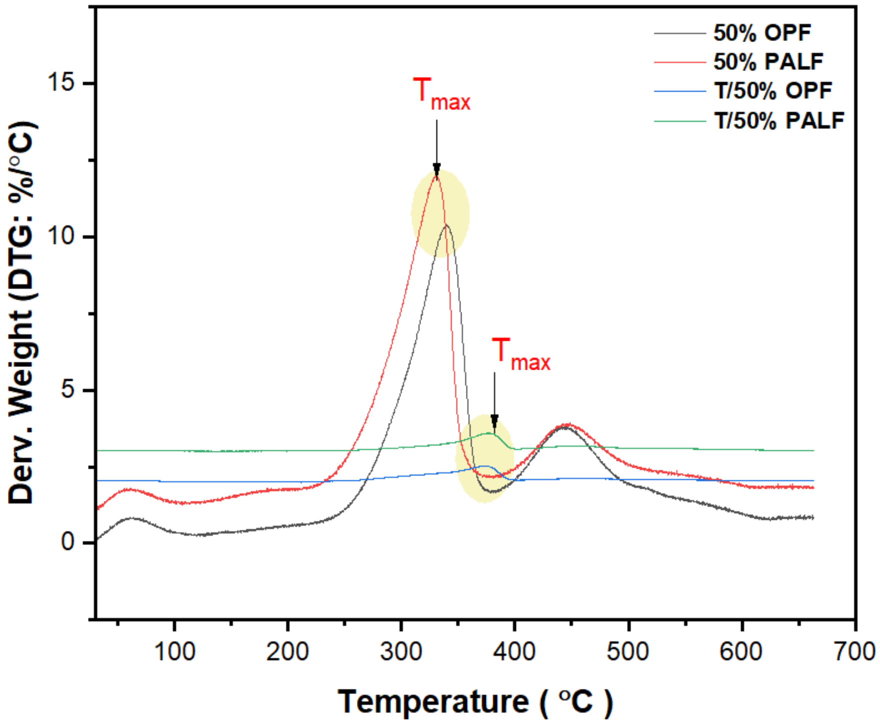

Fig. 9. DTG curves of the untreated and treated pure composites.

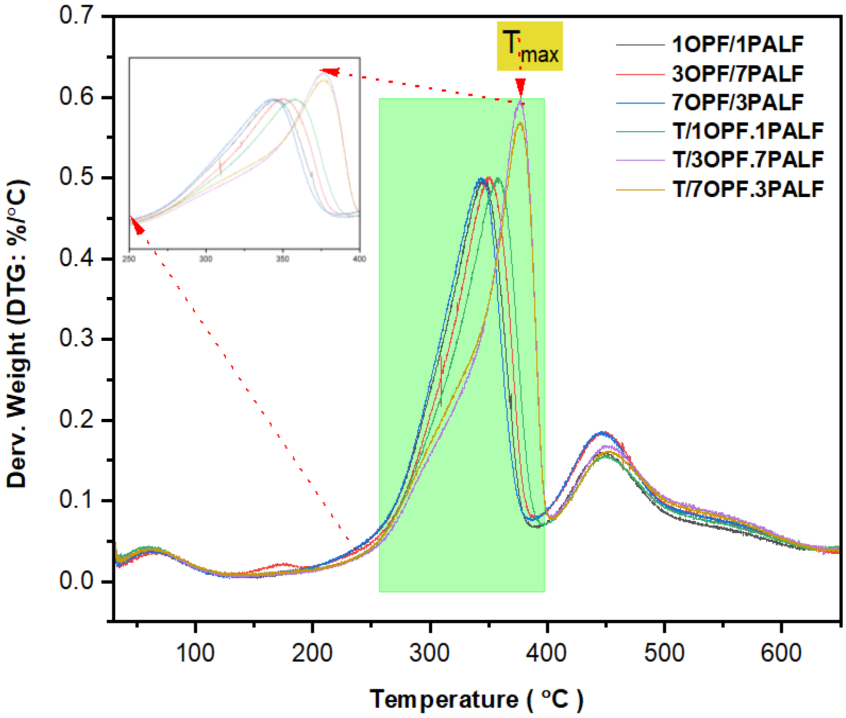

Fig. 10. DTG curves of the untreated and alkali-treated hybrid composites.

Table 1. Onset temperature and temperature at maximum thermogravimetric decomposition peak (T_{max}) and yield char for TGA and DTG data.

Sample ID	T_{onset} (°C)	T_{max} (°C)	Yield char % at 600°C
50%OPF	282.85	337.25	37.81
T/50%OPF	329.07	371.38	40.02
50%PALF	290.39	335.42	35.99
T/50%PALF	339.57	376.22	38.22
1OPF/1PALF	290.46	338.50	38.49
T/1OPF.1PALF	317.94	361.30	43.25
3OPF/7PALF	286.92	335.82	35.23
T/3OPF.7PALF	335.71	374.82	36.42
7OPF/3PALF	294.43	342.30	35.06
T/7OPF.3PALF	331.80	376.25	36.08

4.4. Mechanical Characterisations

The mechanical properties (tensile, flexural, impact strength) of untreated and treated fibres composites are shown in Figs. 11, 12 and 13, respectively. The T/50% PALF exhibited higher flexural stress (78.2 MPa) among other fibre composites, while the flexural modulus was (6503 MPa). The efficiency of alkali treatment on fibres surface due to the reaction with (-OH) groups produces hybrid fibres more hydrophobic and consistent with the BPHR matrix. In contrast, the flexural strength and modulus for treated pure composite (T/50%OPF) exhibited a slight reduction (51.9 MPa and 4495.5 MPa) compared to untreated composite (50%OPF) (55.2 MPa and 5040.9 MPa). On the other hand, The treated hybrid composite (T/3OPF/7PALF) presented the most excellent performance among the other hybrid composites due to high-quality adhesion between the ratio of 3:7 PALF and OPF, which led to higher flexural strength. As a result, the flexural strength of hybrid treated composites enhanced significantly compared to untreated ones. Following, the flexural strength of T/1OPF.1PALF increased by 19%, while the flexural modulus increased by 11% compared to those of corresponding untreated hybrid composites. The significant improvements in flexural stress and modulus for treated hybrid composites is attributed to enhanced interfacial adhesion, which produced efficient stress transfer between the matrix and the fibres. In their research findings, Ramlee et al. [39] reported that the treated silane hybrid composites (5OPEFB:5SCB) exhibited the greatest flexural and compressive strength 16.82 MPa and 6.53 MPa among all other composites. Effect of fibre treatments on the Oil Palm Fibre (OPF) composite exhibited a maximum tensile strength of 40 MPa, the tensile modulus of 1.3 GPa and elongation at break of 9% when the fibres were treated, respectively, with permanganate, mercerisation and latex coating [40].

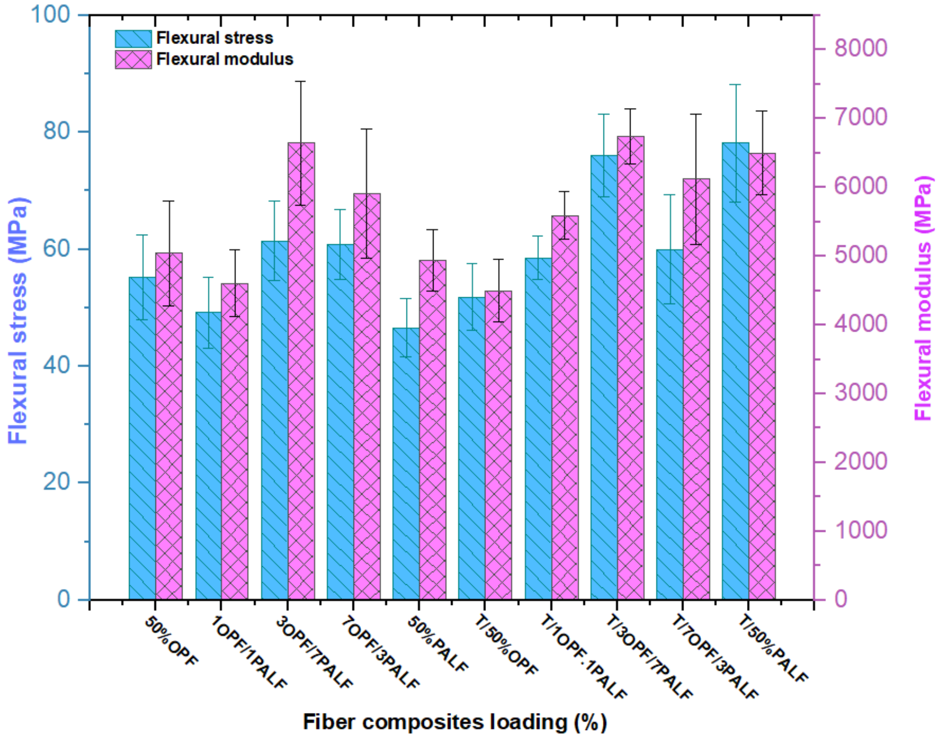

Fig. 11. Flexural stress and flexural modulus for pure and hybrid fibre composites.

The findings of tensile strength and moduli and elongation at break are displayed in Fig. 12. As shown in the figure, the T/50%PALF composites exhibited the greatest tensile stress (42.2 MPa) along with treated and treated samples. In contrast, the tensile strengths of treated (T/50%OPF) and untreated (50%OPF) pure composites increased by 184.5% and 173%, respectively, compared to the BPHR matrix (11.07 MPa). The tensile strength values for treated composites T/1OPF.1PALF; T/3OPF/7PALF; T 7OPF.3PALF were 35.96 MPa; 30.36 MPa, and 22.93 MPa, respectively, while the corresponding untreated composites were 20.69, 24,01 and 23.98, respectively. The tensile modulus for treated pure composite (T/50%PALF) and (T/1OPF/1PALF) showed the highest values (8131.33 MPa and 7482.25 MPa), respectively, among all composites. In contrast, the elongation at break for pure treated composite (T/50%PALF) increased by 13% among all composites.

Rizal et al. [41] stated that the treatment of cattail fibre (Typha species) with 5% NaOH solution into Biophenolic resin and the tensile strength increased from 29.2 to 37.4 MPa while noticing that the treatment with 5 wt.% KH570, the tensile strength and flexural strength were 36.1 and 54.7 MPa. Siakeng et al. [42] observed in their findings that alkali-treated hybrid (3CF 3/7PALF) composites exhibited the greatest tensile strength (30.3 MPa) while Young's modulus was about 5.2 GPa compared to all hybrids composites. On the other hand, Ramlee et al. [39] showed that the hybridisation of silane-treated fibre composites (7OPEFB/3SCB) exhibits the greatest efficiency in tensile strength and modulus with the greatest tensile strength and modulus 11.67 MPa and 1348.43 MPa. Similar recent work was performed by Awad et al. to investigate the improvements for alkali (NaOH) treated with the hybrid and pure OPF and PALF fibres on the biophenolic resins. They noticed that the hybrid composites (NaOH/1OPF.1PALF) showed the highest flexural strength, which was 99.8 MPa while flexural modulus was 8813.1 MPa [10].

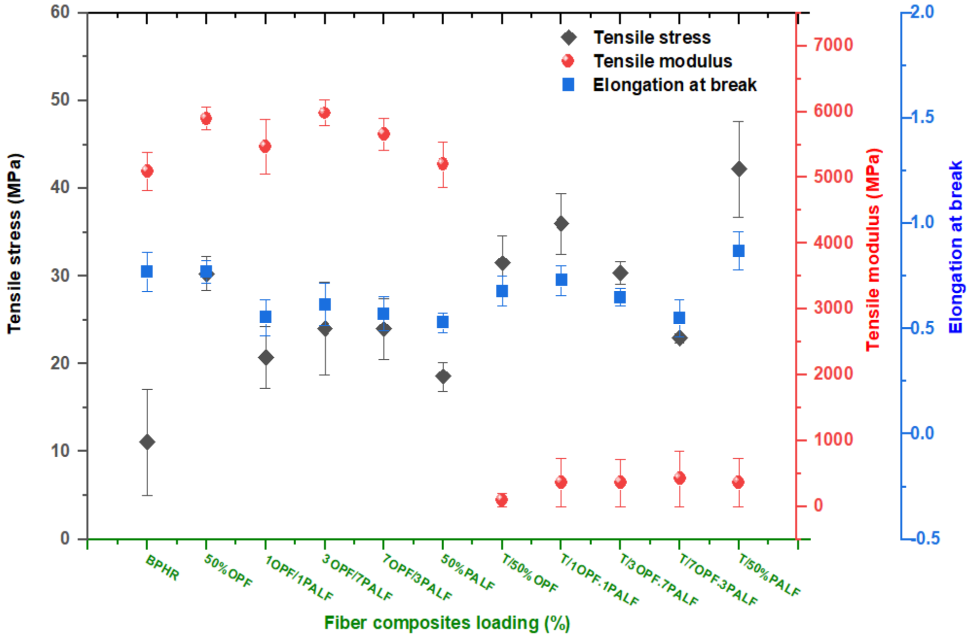

Fig. 12. Tensile strength, tensile modulus, and elongation at break for untreated and treated composites.

The results of the impact strength test for the treated and treated fibre composites are shown in Fig. 13. Among pure and hybrid composite samples, (the T/1OPF.1PALF) sample exhibited the improved combination for reaching the greatest impact strength. It can be seen from Fig. 13 that the highest impact strength values observed in treated pure composite (T/50%PALF: 7.1 KJ/m^2) and hybrid composite sample (T/1OPF.1PALF: 7.2 KJ/m^2). This could be assigned to the capability of T/1OPF.1PALF to elevate further impact energy through unexpected load than other samples. The impact strength of T/50% OPF was 5.9 KJ/m^{2,} while the 50% OPF was 5.1 KJ/m^2. On the other hand, the hybrid composite samples (T/3OPF.7PALF and T/7OPF.3PALF) exhibited a slight increase in impact strength (5.2 and 5.3 KJ/m^2) compared to those untreated corresponded hybrid composites (3.8 and 4.1 KJ/m^2). Mittal and Shihna [35] investigated the impact strength efficiency for wheat straw fibre-reinforced epoxy composites. The impact strength of the 1% NaOH alkali-treated fibre composites significantly improved from 25.2 to 28.7 J/m. In contrast, 3% NaOH treated composite, and the impact strength increased from 28.7 to 29.6 J/m while the impact strength increased up to 31.2 J/m with fibre composite treated with 5% NaOH alkali solution. Further evidence was investigated by Prabhu et al. [44] to investigate the improvements for impact strength on the characterisations for treated hybrid fibre composites. They reported that the impact strength for the treated hybrid composite (the Snake Grass Fibre: SGF/Waste Tea Leaf Fibre: WTLF) was increased by 77.4% compared to other samples.

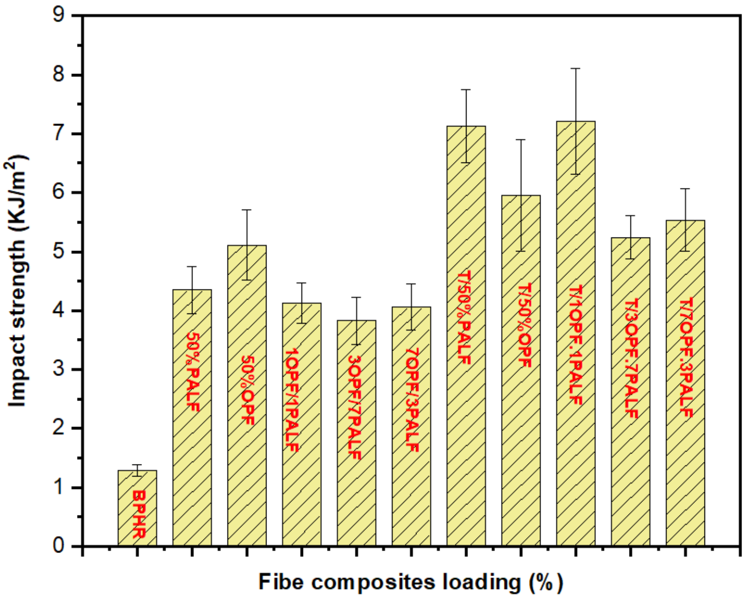

Fig. 13. Impact strength for untreated and treated pure and hybrid fibre composites.

5. Conclusions

Untreated and treated OPF and PALF fibres reinforced bio-phenolic composites and hybrid composites were fabricated using compression moulding technique, and their thermal and mechanical properties were characterised. The results obtained from the various tests lead to the following conclusions:

1. FTIR results indicated that alkali treatment shifted the chemical composition of fibre composites.

2. From DMA results, the treated hybrid fibres composite displayed the lowest damping values compared to those of other fibres composites while they showed the highest storage modulus values.
3. The flexural and tensile strength of alkali-treated fibres composites increased compared to those untreated fibres composites, which were attributed to results from enhanced interfacial adhesion. The treated composites (T/50%PALF) sample's tensile and flexural moduli showed significant improvements than other composites. Compared to untreated fibres composites, the tensile and flexural strength for T/50%PALF were increased by 42.19% and 40.9%, respectively. In addition, the impact strength increased significantly by 457% and 463% for T/50%PALF and T/1OPF.1PALF, respectively.
4. Contrasted with untreated fibre composites, decomposition the maximum temperature was significantly increased by 11%, 12%, 28% for treated samples (T/50%PALF, T/3OPF.7PALF, T/7OPF.3PALF), respectively. The novel comprehensive for this indicated that the treatments with alkali solution for hybrid fibre composites to be compared with pure fibre composites prepared along a direction for developing novel composites down the improvement of current materials.
5. Furthermore, the hybridisation of natural fibres incorporated into the BPHR matrix showed better adhesion, which was noticed from the mechanical and chemical tests in this experimental work. Finally, it can be concluded that the chemical treatments for hybrid fibres (T. OPF/PALF) reinforced BPHR matrix are promising and have excellent potential in the world of composites.
6. The current work presented exhibits cost-efficient material advance, which is occupied as the most important concern and can be successfully applied in the auditory range of the building, including soundproof panels applications.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

The raw/processed data required to reproduce these findings cannot be shared at this time due to technical or time limitations.

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