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RESEARCH ARTICLE

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A comparative evaluation of chemical, mechanical, and thermal properties of oil palm fiber/pineapple fiber reinforced phenolic hybrid composites

Mohammad Jawaid[1] | **Sameer A. Awad**[2] | **Mohammad Asim**[1] | **Hassan Fouad**[3] | **Othman Y. Alothman**[4] | **Carlo Santulli**[5]

[1]Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), University Putra Malaysia, Serdang, Selangor, Malaysia

[2]Chemistry, School of Science and Technology, University of New England, Armidale, New South Wales, Australia

[3]Applied Medical Science Department, Community College, King Saud University, Riyadh, Saudi Arabia

[4]Chemical Engineering Department, College of Engineering, King Saud University, Riyadh, Saudi Arabia

[5]Geology Division (SST), School of Science and Technology (SST), Università degli Studi di Camerino, Camerino, Italy

Correspondence
Mohammad Jawaid, Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP) University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
Email: jawaid@upm.edu.my

Abstract

In this paper, oil palm fiber (OPF) and pineapple fiber (PALF) reinforced biophenolic resin (BPHR) composites and hybrid composites were fabricated by hand lay-up technique. Structural, thermal and mechanical properties of pure and hybrid composites analyzed by Fourier transform infrared (FTIR), thermal gravimetric analyzer (TGA), dynamic mechanical analyzer (DMA), and universal testing machine. Achieved results indicated that OPF/PALF hybrid composites show better properties as compared with pure composites. It was observed that the tensile and flexural characterizations improved with incorporating OPF and PALF fibers into BPHR composites in comparison to the neat BPHR matrix. The results of the thermal stability obtained from TGA tests showed that the reinforcement of pure fiber composites (OPF and PALF) and hybrid composites (OPF/PALF) in BPHR matrix were improved in comparison to that of neat BPHR matrix. The final decomposition temperature of 50% OPF and 3OPF/7PALF was the highest among all other composites (415.80 and 415.42°C). On the other hand, the residual amount of hybrid composite (1OPF/1PALF) was (24.43%), while the lowest residual amount exhibited in pure composite (50% PALF), which was 20.08%. The reinforcement of pure composite and hybrid composites into BPHR also improved the storage and loss moduli; however, the pure composite sample (50% OPF) exhibited a more significant increase than other composites loadings. Furthermore, the damping factor was reduced significantly by the reinforcement of hybrid composites over pure composites. This study showed that obtained hybrid composites are suitable to apply in various structural and nonstructural applications.

KEYWORDS

biophenolic resin, chemical changes, natural fiber composites, tensile strength, thermal stability

1 | INTRODUCTION

Natural fibers have been broadly utilized as alternative and efficient fillers in polymer composites.[1] Commonly, polymers are fabricated with natural to secure preferred thermal, mechanical, and electrical characterizations in fibers or particles. The characterizations of composite materials largely rely on their corresponding fibers properties.[2]

Therefore, natural fibers consider the most promising reinforcing materials for polymers utilizing to enhance their strength, stiffness, and loading capacity.[3] Natural fibers are utilized as an alternative for glass fiber in epoxy or polymer composites, able to provide attractive improvements according to eco-friendly, low energy consumption and renewability and have low density, are rapidly developing as possible strengthening materials in composites manufacturing.[4–6] Furthermore, they convey biodegradable conditions to polymer composites, giving them a significant improvement compared to synthetic fiber-based composites from an environmental perspective.[7] According to the desirable properties such as packaging, construction, and textile in recent years, which are due to natural fibers, several researchers depended in their academic and industrial researches in using natural fibers as composites as a result of several improvements: low densities, recyclability, biodegradability, low cost, and high strength to mass ratios,[8,9] and having a low environmental effect, and sustainable and good thermo-physical characterizations.[10,11]

Pineapple leaf fibers (PALF) and oil palm fibers (OPF) are among the most readily available natural fibers in Malaysia and other Southeast Asian countries. They have the highest potential to be used as a reinforcement material in polymer composites.[12–15] Incorporating waste fibers into polymers makes them very cost-effective, enhances their thermal and mechanical properties and transforms them into green composites.[12,16] PALF has excellent mechanical characterizations as a result of the unusual chemical components, such as cellulose (70–82%), lignin (5–12%), and ash (1.1%).[13,17]

Oil palm is grown in about 42 countries and covers 11 million hectares, involving West Africa, South East Asia, and Latin America.[18–20] The plantations of palm oil that were distributed throughout the regions had become an essential role in the economy of Southeast Asia. Indonesia and Malaysia were the largest producers of palm oil in the world. Thus, this indicates generally that palm oil was a higher crop.[21] It is likely to understand by what means OPF fiber influences polymer composites and expects OPF fiber to be utilized to rehabilitate structural concrete construction elements.[22] At present, the use of a bunch of empty fruit of palm oil as fuel and fertilizer and cover material in the manufacture of fiber because the remnants of these waste materials can cause environmental concerns.[22]

The hybrid composites showed improved mechanical characterizations than fiber-based composites.[23] Rozman et al[24] studied the mechanical characterizations of oil palm/glass fiber hybrid composites. They noticed that improving the loading of OPF from 10 to 40% in the biophenolic resin (BPHR) decreased the tensile strength and improved the modulus. Jawaid et al[25] described that oil palm/jute hybrid composites displayed better mechanical characterizations than monolithic composites. Khalil et al[26] found that incorporating OPF into polypropylene composites showed increasing flexural modulus, but the flexural strength was reduced. Munawar et al[27] reported that PALF loading in biodegradable resin exhibited perceptible improvements in the mechanical properties. Ramlee et al[28] found that the hybridization of OPEFB/SCB composites exhibited better characterization than pure fiber composites. They indicated in their findings confirmed that hybrid composites (7OPEFB/3SCB) showed the greatest tensile modulus and strength, which were 661 and 5.56 MPa, respectively, with fewer porous areas and voids in contrast to pure composites. Ramlee et al[29] investigated the improvements of mechanical and morphological properties hybrid fibers (sugarcane bagasse; SCB and oil palm empty fruit bunch; OPEFB) strengthened bio-phenolic composites. They found that the hybridization of the 7OPEFB/3SCB composite displayed offered the greatest achievement on tensile strength (11.67 MPa) and modulus (1348.43 MPa).

In terms of eco-friendly materials, researchers attempt to discover and investigate alternative utilization of abundant fibers from sustainable resources in Malaysia to produce hybrid composites. Regarding this paper, the study aims to fabricate pure fibers composites to be compared with hybrid composites, which includes OPF and PALF composites reinforced with BPHR. Though, the major purpose of this study was to examine the impact of hybridization on the chemical, thermal and mechanical characterizations of pure and hybrid composites based on OPF and PALF. However, the influence of hybridization on the mechanical and thermal characterizations of natural fiber composites was investigated by a number of researchers; most of the experiments were focused on interlaminar hybrid composites.

Therefore, this research work has been prepared with the idea to create high-efficiency composites, able to provide effective boards for thermal insulation, more resistant to the environment, especially in urban construction field, where increasingly a better sustainability profile is sought for.

2 | EXPERIMENTAL

2.1 | Materials

BPHR type (Grade: PH-4055) was provided by Chemovate Girinagar, Bangalore, India. OPF utilized in this research work was provided by the Malaysian Palm Oil Board (MPOB). PALF type *Ananas comosus* with a density of 1.07 g/cm^3 were obtained from Tamil Nadu state of South India. Natural fibers used in this study were applied in as-received conditions without further treatment of the surface. The chemical formation and mechanical physical characterizations of OPF and PALF composites are displayed in Table 1.[8,30–33]

2.2 | Preparation of pure and hybrid composites

OPF and PALF fibers are utilized as enhanced materials in the fabrication of bio-phenolic resin composites. First, OPF and PALF were crushed into 0.8–1 mm, utilizing a grinding machine; the content of moisture for the fibers was controlled at 6–8%. Then, OPF and PALF composites were fabricated utilizing a stainless metal plate within 15 × 15 × 3 mm. The 3 mm stainless steel plate was positioned into hydraulic pressure with a hot press at 160°C. The samples were removed from the stainless metal plate by pressing for 8 min, then stored for cooling at room temperature, and after that, specimens were cut for analysis based on the standard ASTM. The compositions of pure composites (OPF and PALF) hybrid composites (OPF/PALF) are illustrated in Table 2. Figure 1 shows a schematic diagram of OPF and PALF bio-epoxy composite.

3 | CHARACTERIZATIONS

3.1 | Fourier transformed infrared spectroscopy

The changes in chemical and functional groups of the pure and hybrid composite were evaluated utilizing capability method by applying FTIR spectrometer type; Thermo scientific Nicolet 6700 Instrument with attenuated total reflectance (ATR). The resolution range of spectrum settings was 4000 to 400 cm^{-1}.

TABLE 1 The properties of natural fibers utilized in this work[5,27–30]

Properties	OPF	PALF
Density (g/cm^3)	0.7–1.5	1.07–1.50
Diameter (μm)	150–500	20–80
Tensile strength (MPa)	50–400	290.61
Young's modulus (GPa)	1–9	5.83
Elongation at break (%)	8–18	1.6–4
Cellulose content (%)	43.7	70–82
Lignin content (%)	13.3	5–12
Hemicellulose content (%)	29	18.8

Abbreviations: OPF, oil palm fiber; PALF, pineapple leaf fiber.

3.2 | Thermogravimetric analysis

The thermal stability of pure composites (OPF and PALF) and hybrid OPF/PALF composites was evaluated utilizing a thermogravimetric instrument type (Q500 TA Instrument, TGA). The specimens weight was ranged between 5 and 10 mg. The trial was performed at a heating rate of 20°C/min with a range of temperature of 30–600°C under N_2 atmosphere.

3.3 | Dynamic mechanical analysis

The tests of dynamic mechanical analysis (DMA) characterization were carried out utilizing a TA (DMA Q 800) instrument, based on the standard of ASTM D4065-01, as a temperature function. The dimensions of specimens were about 60 × 12.5 × 3 mm^3 to estimate the viscoelastic performance of pure and hybrid composites. DMA samples were performed in the bending mode (3-points), and the temperature was about 30–150°C with a heating rate of 5°C/min.

3.4 | Tensile testing

The specimen dimensions measured were 120 × 20 × 3 mm. Five samples as an average replicated for each test (tensile strength and modulus). All specimens were positioned for preparation at a temperature of 22°C and relative humidity of 50% by way of ASTM standard prior to testing initiated. The testing was performed by utilizing a universal examination machine type; 5 kN Bluehill INSTRON.

3.5 | Flexural testing

The flexural samples with dimensions of 280 x 52 x10 mm were synthesized and examined in combination with ASTM D790. The samples were tested by utilizing type a 30 kN Bluehill Instron 5567 universal testing machine. The crosshead speed was subjected at 2.0 mm/min. Thus, for this work, the crosshead motion was 4.26 mm/min. The tests were performed and controlled at 23°C and 55% relative humidity. For the flexural investigation, five samples were calculated over the average results.

3.6 | Izod notched impact test

For impact properties characterization, samples sizes are 70 × 15 × 8 mm^3 of composites were analyzed utilizing

TABLE 2 The compositions of OPF, PALF, and BPHR composites

Reference sample	OPF (wt%)	PALF (wt%)	BPHR (wt%)
BPHR	0	0	100
50% OPF	50	0	50
50% PALF	0	50	50
1OPF/1PALF	25	25	50
7OPF/3PALF	35	15	50
3OPF/7PALF	15	35	50

Abbreviations: BPHR, biophenolic resin; OPF, oil palm fiber; PALF, pineapple leaf fiber.

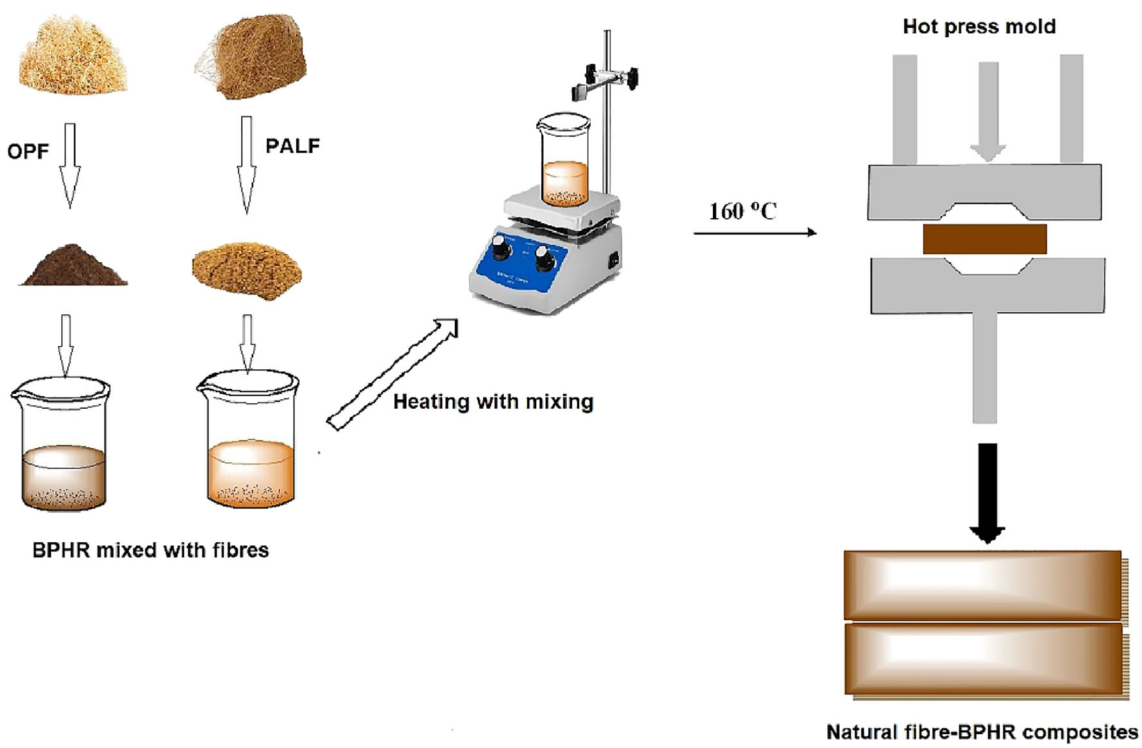

FIGURE 1 Schematic diagram for fabrication of OPF and PALF-bio-epoxy composites. OPF, oil palm fiber; PALF, pineapple leaf fiber

an impact testing machine type: Instron CEAST 9050. The temperature and humidity were recorded at 22°C and 50%, respectively. The dimensions and conditions of the tests were performed according to the standard of ASTM D256-10e1. Five samples for each test as an average of impact load was calculated and demonstrated.

4 | RESULTS AND DISCUSSION

4.1 | FTIR analysis

In this work, in order to explain the effect of natural fibers (OPF and PALF) as additives on the chemical changes in functional groups in improving the surface characterizations of the BPHR matrix, FT-IR analysis was conducted on pure and hybrid fiber composites, as given in Figure 2. This work focuses on examining molecular structures of cellulose, hemicellulose, and lignin, which have the greatest impact on the mechanical properties of fibers as a result of their high tensile strength. The spectra of FTIR were verified with a wavenumber range from 400 to 4000 cm^{-1}. A broad band ranging from 3000 to 3600 cm^{-1} displayed hydroxyl group (—OH) in the structure of cellulosic fibers[17] that can be simply pointed out in every natural fiber reinforced hybrid composite, whereas band from 2800–3000 cm^{-1} showed the existence of C—H bond, which is due to methylene groups.[20] At the band of 1733 cm^{-1} showed a sharp peak, attributable to the carbonyl stretching absorption of carboxyl and ester groups, which is most abundant of hemicelluloses in PALF pure composite reduced considerably with 1OPF/1PALF hybrid composites.[11] Sreekala observed that the OPF pure composite reveals peaks due to

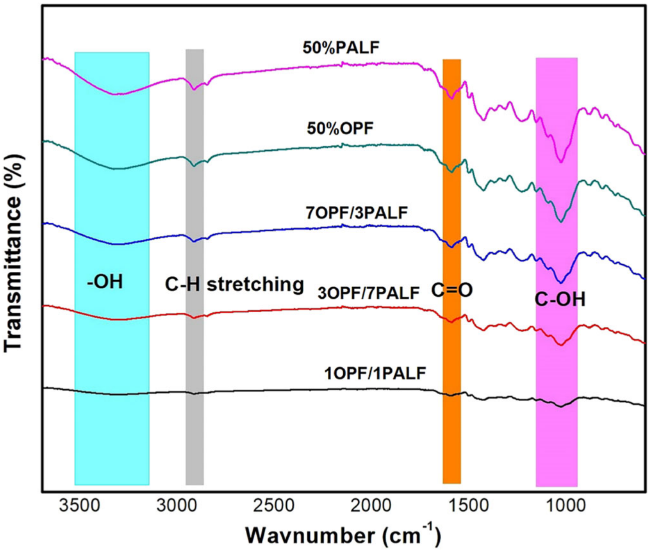

FIGURE 2 Fourier transform infrared (FT-IR) spectrum of pure and hybrid/biophenolic resin composites

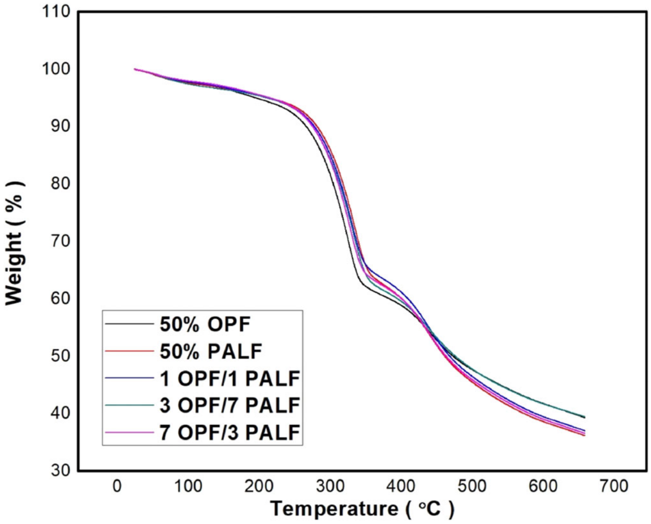

FIGURE 3 TGA curves of pure and hybrid fibers/BPHR composites. BPHR, biophenolic resin; TGA, thermal gravimetric analyzer

stretching of C—O at 770 cm^{-1} and stretching of C—H group at the band of 2850 cm^{-1}, while OPF composite presents another peak at 3350 cm^{-1} caused by the —O—H stretching.[34] Corresponding to Jonoobi, the FTIR spectrum of OPF exhibited a broad peak at 3338 cm^{-1}, which exists in spectra attributed to the group of O—H, while the peaks at 2915 cm^{-1} principally occur from the stretching of the C—H group.[35]

4.2 | Thermogravimetric analysis

TGA is a corresponding technique utilized to examine the thermal stability of pure and hybrid composite materials. The thermal stability of these composites is assessed by TGA in view of the onset of thermal degradation (T_i). TGA graph of hybrid composites (OPF/PALF) is illustrated in Figure 3. The first losses of weight appeared lower than 100°C as a result of the dehydration or evaporation of water molecules in pure composites (PALF and OPF) and hybrid composites (OPF/PALF).[36] From TGA results, the initial thermal degradation of 50% OPF and 50% PALF composites was 35.50 and 30.90%, respectively. On the other hand, the weight loss values at the initial degradation temperature (T_i) of (1OPF/1PALF, 3OPF/7PALF, and 7OPF/3PALF) hybrid composites were 32.99, 34.64, and 34.14%, respectively. Compared with the initial degradation temperature, the 50% OPF single composite exhibited a higher degradation temperature, which was 294.43°C than those of 50% PALF pure composite and hybrid composites. However, at the final degradation temperatures, 1OPF/1PALF, 3OPF/7PALF, and 7OPF/3PALF hybrid composites improved weight loss. However, the temperature range was very elevated (413–416°C), in contrast to the OPF and PALF pure composites, as illustrated in Table 3. The weight loss at the final stage of thermal decomposition (T_f) of pure composites (OPF and 50% PALF) was between (20.56 and 23.94%). While the corresponded T_f values of pure composites were between 415.80 and 413.99°C, respectively, caused by the thermal degradation of cellulose and depolymerization of a BPHR matrix. The maximum final residue was exhibited in hybrid composite (3OPF/7PALF), whereas the lowest residue amount was 35.06% found 50%PALF. On the other hand, the final residue of 50% OPF pure composite was 37.81%, while the residue of the 1OPF/1PALF and 7OPF/3PALF hybrid composites was 35.99 and 35.23% at the final degradation temperature. A higher quantity of accessibility of char in hybrid and pure composites supports retardancy of flame.

Ramlee et al[37] studied the thermal degradation behavior of OPEFB and SCB fibers reinforced BPHR composites. They noticed that the initial decomposition temperature of OPEF/bio-epoxy composite was 245°C, while the final decomposition temperature was 365°C and the percentage of residual mass at 500°C was 20.4%. On the other hand, the initial decomposition temperature of SCB/bio-epoxy composite was 260°C, while the final decomposition one did not exhibit a significant change compared to OPEFB/bio-epoxy composite. However, the residual mass of SCB/bio-epoxy composite showed a slight decrease (19%) than that of OPEFB/bio-epoxy composite.

TABLE 3 Thermal degradation of pure (OPF and PALF) and hybrid (OPF/PALF) fibers composites

System	Degradation temperature (°C) and mass loss (%)				DTG at maximum temperature peak (°C)	Mass residue (%)
	T_i (°C)	Mass loss (%)	T_f (°C)	Mass loss (%)		
50% OPF	282.85	35.59	415.80	20.56	337.25	37.81
50% PALF	294.43	33.90	413.99	23.94	342.30	35.06
1OPF/1PALF	290.39	32.99	413.96	24.43	335.42	35.99
3OPF/7PALF	290.46	34.64	415.42	20.08	338.50	38.49
7OPF/3PALF	286.92	34.14	413.92	23.33	335.82	35.23

Abbreviations: DTG, derivative thermogravimetric; OPF, oil palm fiber; PALF, pineapple leaf fiber.

4.3 | Derivative thermogravimetric analysis

The analysis of derivative thermogravimetric (DTG) for pure composites and hybrid composites are illustrated in Figure 4. The DTG curves peaks showed the temperature decomposition of each pure fiber and fiber hybrid composite. Three peaks were noticed under the temperature range of 80, 270–380, and 430–465°C. The first peak revealed the decomposition under 100°C, achieving its greatest rate of 0.75%/min, stating the existence of hydroxyl molecules in fiber composites.[35] The second peaks were apparent, which indicated the maximum rate of mass loss. The 50% OPF pure composite displayed the highest loss in derivative weights at a lower temperature in the second peak. On the other hand, 1OPF/1PALF, 3OPF/7PALF, and 7OPF/3PALF hybrid composites exhibited degradation rates of DTG 9.9, 10.2, and 10.5%/min. Though hybrid composites demonstrated a low percentage of weight loss, the degradation rate showed the degradation of fibers contents (cellulose and hemicellulose) and the presence of voids in composites maybe make them loosen.[28] After All, in the third phase, the process of decomposition was relatively lower than the second peak; the maximum and minimum decomposition rate of 3.7%/min followed by 411.6°C. In terms of the third peak, hybrid composites (1OPF/1PALF) were verified at a lower temperature, and 3OPF/7PALF and 7OPF/3PALF hybrid composites showed the highest degradation rate. For pure composites (50% OPF and 50% PALF), the DTG values at the maximum temperature peaks (Figure 4) were (337.25 and 342.30°C), respectively, while the hybrid composites (1OPF/1PALF, 3OPF/7PALF, and 7OPF/3PALF) were 335.42, 338.50, and 335.82°C, respectively. Ganan et al[38] investigated the thermal stability (TGA and DTG) for 30 wt% of sisal fibers reinforced epoxy composite. They demonstrated that the fiber-epoxy composites represent an area at 210–350°C related to the decomposition of sisal fiber constituents.

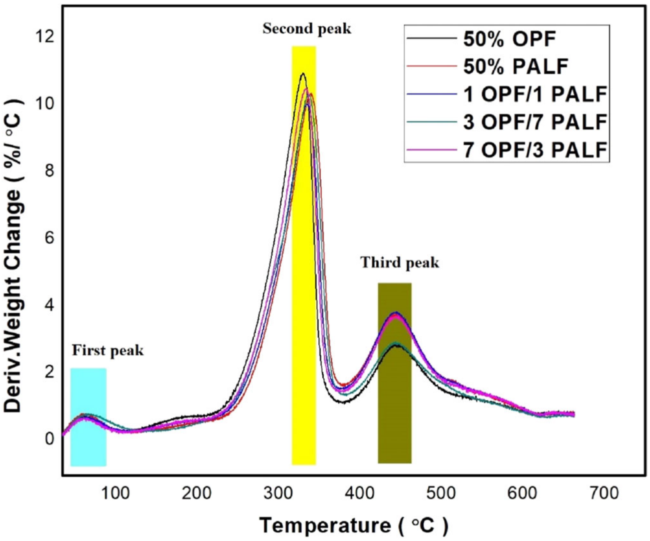

FIGURE 4 DTG curves of pure and hybrid fibers/BPHR composites. BPHR, biophenolic resin; DTG, derivative thermogravimetric

Pereira et al[39] studies thermal stability of hybrid fibers (sisal/ramie)/bio-epoxy composites, they noticed that the DTG curves exhibited two major steps of decomposition: a first phase with an insignificant weight loss within the range of (30–150°C), as a result of the elimination the humidity from the composites while a second phase, which found between 260 and 420°C attributable to the process of pyrolysis. The main decomposition peak shows from the DTG plots, which appears at roughly 337°C for all composites. This indicates that the hybridization did not influence the composites thermal stability. They displayed that the second decomposition stage of hybrid fibers (sisal/ramie)/bio-epoxy composite appears in the range of 270–350°C. Furthermore, this study showed that the main decomposition peaks existed at 337°C, and they were nearly a similar as pure, and the hybrid composites studied in this work.

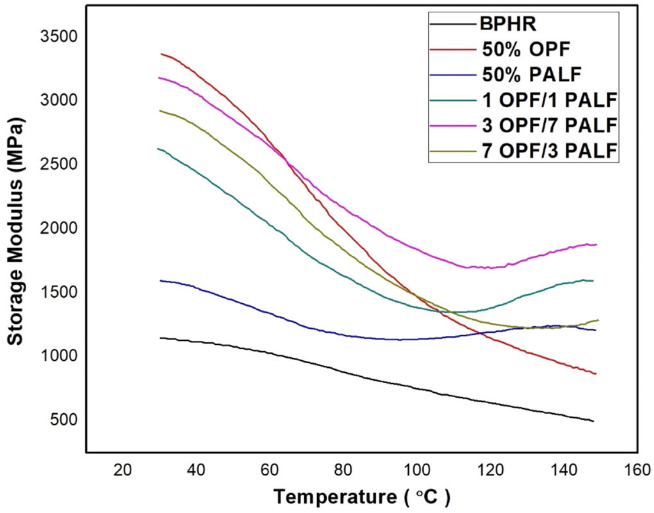

FIGURE 5 Variation of storage modulus of pure and hybrid/biophenolic resin composites

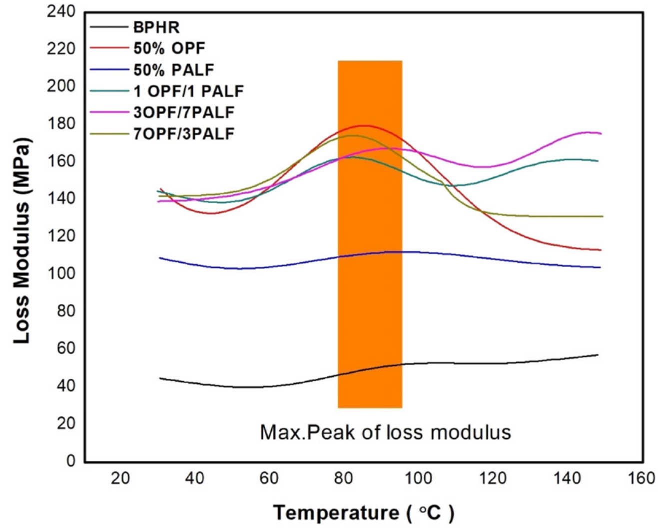

FIGURE 6 Variation of loss modulus of pure and hybrid/biophenolic resin composites

4.4 | Dynamic mechanical analysis

The DMA gave more insight into their viscoelastic properties as well as the morphologies of natural fibers composites. The variations of the storage modulus and loss modulus of the pure and hybrid fibers composites after curing with temperatures is shown in Figures 5 and 6. It is found that the growing content of pure fiber composites (OPF and PALF) in the BPHR matrix elevated the storage modulus though it consistently decreased below that of BPHR. The BPHR matrix showed the lowest storage modulus, which was 1150 MPa. On the other hand, the pure composites (50% OPF) exhibited a higher storage modulus (3371.35 MPa) among all other composites and the BPHR matrix. In comparison, the storage modulus of pure composite (50% OPF) was 1598.13 MPa, as shown in Figure 5. On the other hand, the storage modulus values of hybrid composites (1OPF/1PALF, 3OPF/7PALF, and 7OPF/3PALF) were 2618.13, 3171.83, and 2926.48 MPa, respectively, as shown in Figure 5. In contrast, the hybrid composite (3OPF/7OPF) improved the storage modulus by 175.8% than that of the pure BPHR matrix.

Loss modulus is the viscosity a material degree, which can be described in the same way as the loss of energy when heat under pressure.[40–42] A great loss modulus refers to the behavior of viscous, therefore observed the properties of damping.[43,44] From Figure 6, it can be seen that pure composite (50% OPF) exhibited a higher loss modulus among all composites, which shifted toward a higher temperature, possibly attributable to the greater ratio of natural fibers enhancing the internal fraction.[38] On the other hand, hybrid composites (1OPF/1PALF) showed a peak at a lower temperature. The reason may be the hybridization of 1OPF/1PALF on BPHR composites have been observed that OPF and PALF pure composites enhanced the loss modulus. From Figure 6, the addition of OPF and PALF to the BPHR matrix enhanced in reducing the curing degree and transition glass temperature (T_g).

The damping factor values (tan δ) of all types of natural fibers composites are plotted against the temperature, as shown in Figure 7. The results present only one peak, implying one T_g of the blends. We also notice that the T_g of hybrid composites (OPF/PALF), pure composites (OPF and PLAF) is greater than the pure BPHR matrix. 50% OPF composite showed a higher damping factor (tan δ) than other samples. It is maybe caused by the heterogeneous distribution of OPF that impacted the strengthening and flow of the BPHR matrix. Figure 6 showed the damping curve behavior, its extend to its glass transition peak. In addition, it falls in the rubbery area, offering the frozen phase to the mobility phase of the BPHR matrix. Furthermore, there is no characterized structure continues of polymeric materials in terms of the rubbery stage.[32] A higher value of the impact factor (tan δ) indicates a greater molecular mobility degree, and pure BPHR composite exhibited the lowest peak, which involves the minimum mobility of molecular.[32]

4.5 | Tensile properties of pure and hybrid composites

In this work, OPF and PALF pure fibers and OPF/PALF hybrid fibers are used as modified fillers to improve the natural mechanical of BPHR composites. Hence, the mechanical characterizations, involving the tensile, flexural characterizations, and extension at break of the pure composite (OPF and PALF) compared to the hybrid composites (OPF/PALF), were illustrated in Figure 8. The tensile strength of BPHR displayed the lowest tensile strength over all pure and hybrid composites. The presence of hybrid composites (50%OPF) displayed a high tensile strength of 30.30 MPa compared to 50% PALF, which was 18.57 MPa. On the other hand, for the hybrid fiber composites, 3 OPF/7PALF samples exhibited a slightly higher tensile strength of 24.1 MPa than other samples (7OPF/3PALF and 1OPF/1PALF) hybrid composites, which were 23.98 and 20.69 MPa, respectively. Young's modulus decreased obviously for pure composite (50% OPF) over all natural fiber composites and phenolic resin. The Young's modulus of the pure composite sample (50% OPF) and hybrid composite samples (3OPF/7PALF) was reduced by 40.43 and 32.73%, respectively, while Young's modulus of

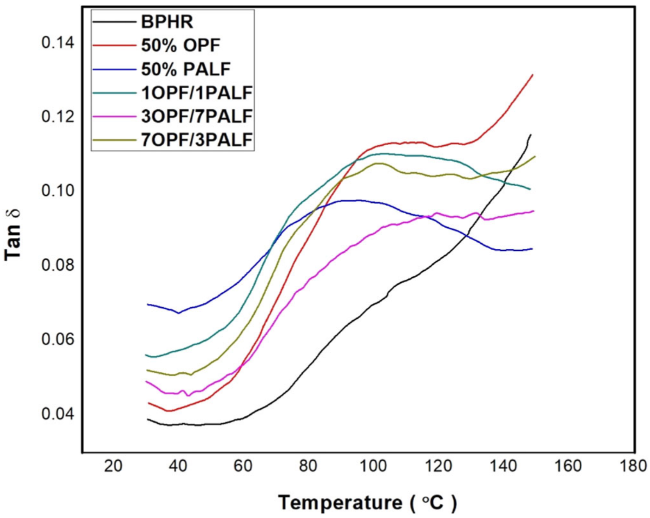

FIGURE 7 Impact factor (tan δ) of natural versus temperature of pure and hybrid/biophenolic resin composites

1OPF/1PALF, 7OPF/3PALF, and 50% PALF increased by 43.88, 16.25, and 17.82%, respectively, in comparison to BPHR sample. There is no change in extension at a break of 50% OPF in contrast to the pure BPHR sample. On the other hand, the values of extension at break were decreased by 28.57, 25.97, 19.48, and 31.17% for 1OPF/1PALF, 3OPF/7PALF, 7OPF/3PALF, and 50%PALF composites, respectively. As a result, 50% OPF pure composites showed better tensile strength while 1OPF/1PALF hybrid composite exhibited better Young's modulus with good fiber/matrix interfacial bonding (Figure 8). The drop in tensile strength of 7OPF/3PALF and 50% PALF composites may be caused by a higher percentage of fibers that are incapable to be appropriately blended with the matrix. This can be attributed to the insufficient interfacial adhesion of the BPHR particles formed by phase separation to the resin matrix, which results in weaker load transfer capability.[36] Giridharan[45] assessed hybrid (ramie/glass) fiber with different loadings (20:80% and 30:70%) reinforced epoxy composites by flexural and tensile tests, he observed that the hybrid composites with loading 30:70%, displayed higher mechanical characterizations than pure composites. Pereira et al[39] investigated the improvements of mechanical characterizations for the hybrid fibers (Sisal/Ramie: S/R, Sisal/Curauá: S/C, and Sisal/Glass: S/G) filled epoxy composites. They reported that the tensile strength increased by 24.83% for hybrid composite (S/R) in contrast to pure composite (S), while the tensile strength increased by 34.98 and 43.99% for hybrid composites (S/C and S/G), respectively. Benkhelladi et al[46] investigated the improvement the mechanical characterizations of the flax, jute, and sisal reinforced composites. They noticed that the tensile strength tests were 35.85 MPa and 1540 MPa, 41.08 MPa and 1660 MPa, and 29.96 MPa and the tensile modulus tests were 1290 MPa for flax, jute, and sisal fiber strengthened epoxy composites, respectively.

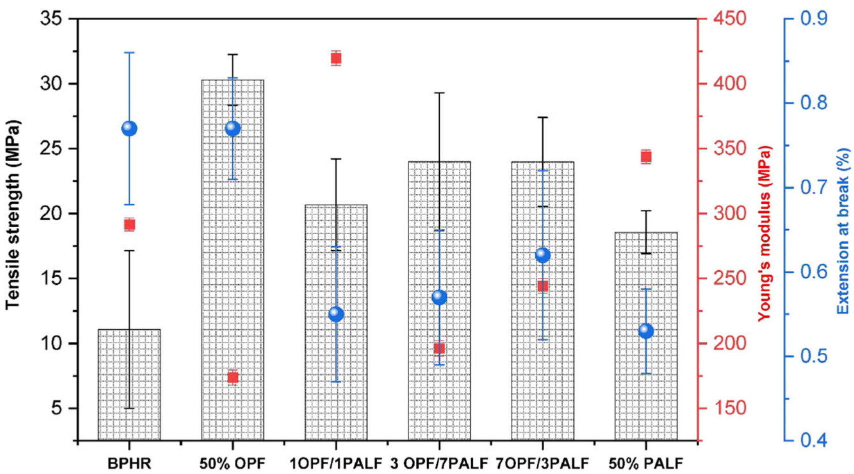

FIGURE 8 Tensile strength, Young's modulus, an extension at break of pure and hybrid/biophenolic resin composites

4.6 | Flexural properties of pure and hybrid composites

The flexural strength and modulus of pure composites (OPF and PALF) and hybrid composites (OPF/PALF) compared to pure BPHR matrix are presented in Figure 9. As it is obviously shown that the flexural strength and flexural modulus of the 3OPF/7PALF hybrid composite exhibited the highest values than all other composites. On the other hand, The flexural strength of 3OPF/7 PALF hybrid composites was 23% higher than that of the BPHR sample. The value of the lowest flexural strength was observed utilizing 1OPF/1PALF hybrid composite, which was 51 MPa, only a 1% increase from the pure BPHR. The flexural strength of the hybrid composite with the incorporation of 1OPF/1PALF was slightly lower than the 50% OPF and 50% PALF composites. The flexural strength of PHE was 50.68 MPa, while 50% OPF and 50% PALF composites were 52.25 and 46.54 MPa, respectively. On the other hand, 3OPF/7PALF and 7OPF/3PALF hybrid composites displayed the greatest flexural strength (61.41 and 60.82 MPa) in comparison to that of 1OPF/1PALF hybrid composite (49.21 MPa), as shown in Figure 9. Related work was achieved by Siakeng et al[42] studied the improvements in flexural strength of PALF and were filled into polylactic acid (PLA) material; they reported that flexural strength reduced at the incorporation of coir fibers (CF). For example, the flexural strength of PLA reduced from 27.87 to 24.6 MPa and 24.64 MPa in the 30% CF composite and 7CF/3PALF hybrid composite, respectively.

With the addition of 50% OPF to pure BPHR, the flexural modulus of BPHR reduced from 5176.48 to 5040.93 MPa, which is shown a slight decrease of 2.64%, whereas with the incorporation of 50% PALF, the flexural modulus of BPHR sample decreased from 5176.48 to 4937.51 MPa, which was reduced by 4.62%. In contrast, the flexural modulus of hybrid composites (1OPF/1PALF) decreased by 11% compared to those of 3OPF/7PALF and 7OPF/3PALF composites, which were increased by 28.36 and 14.13%, respectively.

4.7 | Impact strength

Impact strength is described as the toughness of fracture measure of materials when utilizing an impact loading. It is greatly affected by the material nature, which is immediately associated with its toughness. It represents the cracks formation medium along with the stress transformation.[17] The impact strength values of the BPHR sample, pure composites, and hybrid composites were demonstrated in Figure 10. The pure BPHR exhibited very low impact strength than all fiber composites loadings corresponding to PALF, OPF pure composites and hybrid composite (PALF/OPF). The reason is that biophenolic resin has poor impact strength and considers one of the greatest brittle polymers.[36] In terms of pure composite, the 50% OPF reinforcement displayed better impact strength than the 50% PALF fiber-reinforced composite. For the BPHR sample, the impact strength was 1.28 KJ/m^2, while the impact strength values of 50% OPF and 50% PALF pure composites were 5.11 and 4.348 KJ/m^2, respectively. In comparison to the pure composites (50% OPF and 50% PALF), the impact strength values of 1OPF/1PALF, 3OPF/7PALF, and 7OPF/3PALF hybrid composites were 4.12, 3.83, and 4.06 KJ/m^2. However, the 1OPF/1PALF hybrid composite sample observed that

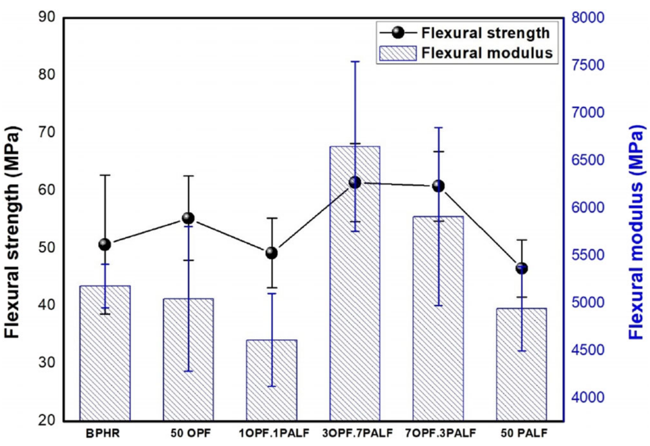

FIGURE 9 Flexural strength and modulus of pure and hybrid/biophenolic resin composites

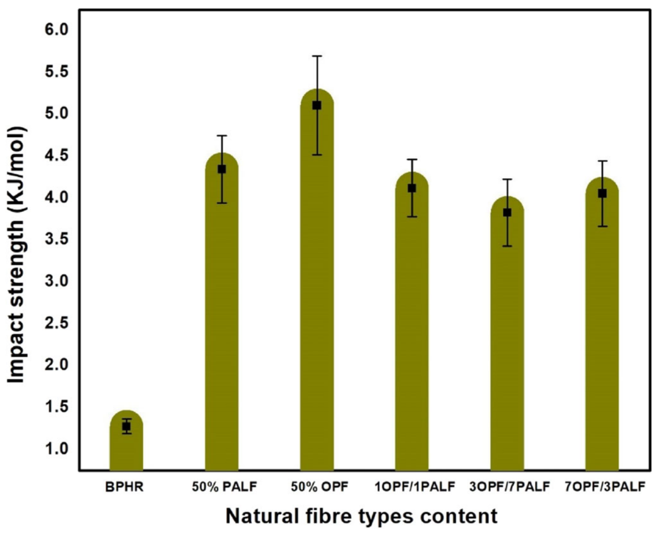

FIGURE 10 Impact strength of pure and hybrid fiber composites

the impact strength decreased across all the samples (Figure 10). The pure composites (50% PALF and 50% OPF) were noted to provide the greatest impact strength values compared to the other samples, which were 299.22 and 239.69%, respectively, higher than that of the pure BPHR sample. It was observed that the hybridization of the fibers could improve the feature of impact strength by reason of the greatest interfacial adhesion between the BPHR matrix and hybrid fibers. Asim et al[44] analyzed the impact strength of date palm fiber (DPF)/ BPHR composites; they found that the resistance of impact dropped after rising loading of DPF from 50 to 60%.[44]

5 | CONCLUSIONS

In this research, the effect of reinforcing single fibers, oil palm (OPF) or pineapple leaf (PALF) fibers, and hybrid fibers (OPF and PALF) into a bio-phenolic resin (BPHR) on the thermal, mechanical and the viscoelastic characterizations were studied. The chemical changes and interactions are enhancing by including pure and hybrid composites into the pure BPHR matrix. Furthermore, the thermal stability improved in pure and hybrid composites. In regard to the mechanical properties, the addition of pure composite (50% OPF) and hybridization of composite (1OPF/1PALF) enhanced the tensile flexural strength and Young's modulus contrasted to other samples. For 50% OPF composite, the tensile strength was increased by 173.71%. The flexural strength and modulus of the hybrid composites were improved compared to that of single fiber composites. On the other hand, a flexural strength of hybrid reinforced bio-epoxy composites (3OPF/7PALF and 7OPF/3PALF) had increased by 23 and 20%, respectively, compared to 50% OPF composites, which was increased by 3.1%, while for 50% PALF composite, exhibited a slight decrease in flexural strength was around 8%. On the other hand, the greatest flexural modulus was observed for 3OPF/7PALF hybrid composite, which increased by 28.3% compared to pure fiber composites.

Furthermore, 50% OPF exhibited the highest impact strength among all other fiber composites. The pure and hybrid composites showed the greatest storage modulus over all composites due to their greatest interfacial bonding, while the loss modulus was enhanced by incorporating the hybrid fibers in bio-epoxy composites. Tan δ indicated that incorporating pure and hybrid fibers into a BPHR inhibit the BPHR chains mobility, causing lower flexibility, which reduces the damping properties. In this study, results were more encouraging and concentrating on creating the composite for biomass sustainability and future improvement as thermal isolation for building materials. This work proved that OPF/PALF hybrid composites, and OPF and PALF pure composites are appropriate for enhancing mechanical properties and efficient thermal stability performance. In brief, the hybrid fiber composites reinforced bio phenolic composites, which are utilized this work are suitable and sustainable materials for industrial and construction applications.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Mohammad Jawaid https://orcid.org/0000-0001-5348-5740
Sameer A. Awad https://orcid.org/0000-0002-9194-719X
Carlo Santulli https://orcid.org/0000-0002-1686-4271

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