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Review Article

Investigation of Mechanical and Thermal Properties on Novel Wheat Straw and PAN Fibre Hybrid Green Composites

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Grewia optiva wheat straw waste fibre and PAN fibre are combined in this study to create new composite materials. The novel specimens were created in the hydraulic hind moulding machine with varying percentages of mass of wheat straw fibres, PAN fibre (2–8%) in an equivalent ratio with other materials, and Kevlar fibre-based composites (2–4%). Natural fibre-reinforced clothing is getting increasingly fashionable these days; thus, this research is important. In several papers, natural fibre has been stated to have the potential to replace synthetic fibres. Natural fibre reinforcing has also proven to be quite effective as composites. It is currently used in a range of fields, including medical fields, aerospace, and the automobile industry, among others. Synthetic fibres are used. The usage of synthetic fibres such as asbestos and Kevlar has already been linked to mesothelioma, a kind of lung cancer. Many people have died as a result of Kevlar and asbestos. As a result, an effort to replace these materials is ongoing. Fabricated material's mechanical, chemical, physical, tribological, and thermal properties were evaluated.

1. Introduction

Because handling wheat-based waste fibre has become a severe concern for India and the rest of the world, and these materials also pollute the environment, wheat fibre waste material is being used [1]. These compounds have been linked to major rail and highway safety concerns. On the other hand, this wastage is related to natural fibres, and researchers are working on eco-friendly composites because Humans have used natural fibres for thousands of years [2]. Because of their excellent qualities, natural fibres are increasingly used to produce novel composites [3]. Recent synthetic fibres have been investigated and found to have several environmental issues [4]. According to prior examinations and studies, asbestos and Kevlar, which are utilised in various applications, have been linked to the deaths of far too many people [5]. Asbestos and Kevlar were first utilised because of their exceptional physical, mechanical, and chemical properties. Still, additional research has discovered that they cause a range of malignancies and major respiratory difficulties [6]. The World Health Organization (WHO) has placed restrictions on using asbestos after discovering its harmful effects [7]. The disadvantages are the low recycling rate, high cost, and environmental toxicity of this reinforced material. Kevlar has been shown in numerous studies to have a significant harmful influence on human health [8]. Ivy gourd is a fast-growing perennial plant native to tropical East Africa and South Asia and is broadly cultivated for its vegetable and medicinal uses in India. Coccinia grand is this plant's botanical name and is associated with the Cucurbitaceae family. This plant is an energetic creeper and grows to a height of 28 m. It starts flowering after two months of planting and is ready for harvesting after three months. On the other hand, natural fibres are light and easy to shape, less expensive, environmentally friendly, and biodegradable. It also has good tensile strength and a high specific strength [9]. Natural fibres are employed in a variety of applications these days, including plastering, building, construction, and transportation. [10]. It offers several advantages but also disadvantages, such as a higher moisture absorption rate. According to various sources, chemical treatments can change surface characteristics like porosity, tension, wetting, and adhesion strength. Few researchers stated that recent advances in manufacturing instruments, materials, and related technologies are solving the main challenges for deploying Class-II composite resin restorations. It is used in medical applications like dental care. To use the composites inside the human body, developing an innovative matrix system with simplified material for bulk-fill composites is essential. The collected bark fibres were submerged in water to induce microbial degradation for ten days, and a metal teeth brush was used for combing to extract quality fibres. Chemical functional groups were identified through FTIR analysis ranging from 4000 cm^{-1} to 500 cm^{-1}. OH stretching was observed at the peak of 3287 cm^{-1}. C-OH stretching was identified at the peak of 1013 cm^{-1}. The average surface roughness of the fibre was estimated at 4.88 nm through the Park XE 70 model atomic force microscope. Wheat is a major part of our crops and is grown worldwide. But thousands of tonnes of wheat waste fibre are also produced along with its cause, which is very difficult to handle and produces many kinds of pollution [10]. Many researchers stated that epoxy resin is significantly used as a matrix material in various aerospace, shipbuilding, automobile industry, and structural applications. The epoxy and glass fibre is mixed in a ratio of 1 : 1 to obtain the best mechanical properties.

A novel of this research aims to develop a green composite utilised wheat fibre. The mechanical qualities of PAN fibre are utilised in hot gas filtration systems, concrete strengthening, sweater and socks manufacture, and other applications. Despite the fact that PAN has excellent frictional properties, natural fibres have been used as reinforcement materials. Wheat straw and PAN fibres have also been used as reinforcement materials with good results.

2. Materials and Methods

2.1. Materials and Composite Fabrication. Wheat straw fibres were gathered from Ghanotala village in Hamirpur, India. The wheat straw fibre was cut into small pieces and soaked in water for four weeks. Afterwards, the fibre was rinsed in deionized water and dried for two days. To remove any potential contaminants, the recovered fibre was soaked in sodium hydroxide (Noah) for 24 hours [11]. The fibre was chopped for 15 minutes. The natural and PAN fibres were then joined with other elements utilised in the construction of new composite materials (phenolic resin, barium sulphate ($BaSO_4$), potassium titan, ceramic, and mica) [12]. Tables 1 and 2 demonstrate the technique.

2.2. Characterization of Physical-Mechanical and Thermal Properties. The impact test was carried out using a pendulum impact testing machine. The test sample was immersed in oil for two days to measure porosity [13]. A Glun Digital measuring scale was used to determine density. By immersing new samples in water for one day, the standard (ASTMD570-98) was utilised to determine their water absorption [14]. Mechanical parameters were determined using universal testing equipment.

2.2.1. Thermo Gravimetric Analysis. In a nitrogen environment, TGA was done on a TA-80WS (flow rate of nitrogen (N2) = 80 ml/min, heat rate = 30°C/min, temperature = 60–800°C, sample size = 13 mg) [15].

2.3. Testing of Tri-Biological Characteristics of Developed Composites. The tribological properties of samples were tested on a chase machine especially utilised to find the characteristics at different temperatures. The new samples were tested to find wear, recovery, stability, fade, and variability [16]. The load was taken at 700 N, and the temperature maintained for 100–300°C reading was taken after each 50°C interval [17].

2.4. Results & Discussion

2.4.1. Characterizations (Chemical, Physical, Mechanical, and Tribiological) of Wheat Straw Fibre and PAN Fibre/Kevlar Fibre Composites. Figure 1 shows the compressive strength and Shear strength of newly developed composites. The compressive strength of 2% based composites was determined to be the highest for wheat straw-PAN and Kevlar-based composites, while WF-4 (8%) and FK-2 (4%) composites have shown their lowest value. The shear strength has the maximum value for wheat straw-PAN-based composites for WH-2 (4%]) and also shows its strength for WH-4-based composites [18]. As the wheat-PAN fibre heat at low temperature, they expand and heat swelling increases. The tensile strength was observed highest at 4% based on wheat-

Table 1: Composites fabrication detail.

Condition for moulding	Procedure
Mixing condition	The basic braking elements are thoroughly mixed (phenolic resin, wheat straw fibre, PAN fibre/Kevlar, and lapinus substances for ten minutes). They were blended with the remaining ingredients. For another 10 minutes, combine ceramic, potassium barium, potassium titan, and ceramic.
Conditions for moulding	$T = 190^{\circ}$C, pressure = 30 MPa, time = 15 min,
Condition for oven curing	Time = 2 (hours), temp. = 170°C

t = time, P = pressure, and T = temperature.

Table 2: Compositional details of materials.

Samples no.	Kevlar	Wheat	PAN fibre	Ceramic	Lapinus	Potassium titan	Resign	Graphite	Barium
WF-1	0	1	1	5	15	5	10	10	53
WF-2	0	2	2	5	15	5	10	10	51
WF-3	0	3	3	5	15	5	10	10	49
WF-4	0	4	4	5	15	5	10	10	47
KF-1	2	0	0	5	15	5	10	10	53
KF-2	4	0	0	5	15	5	10	10	51

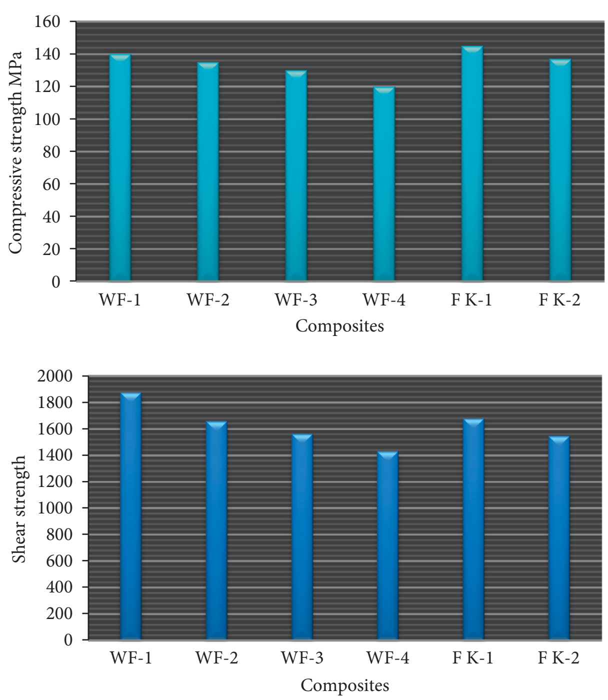

Figure 1: Compressive strength and shear strength of newly developed composites.

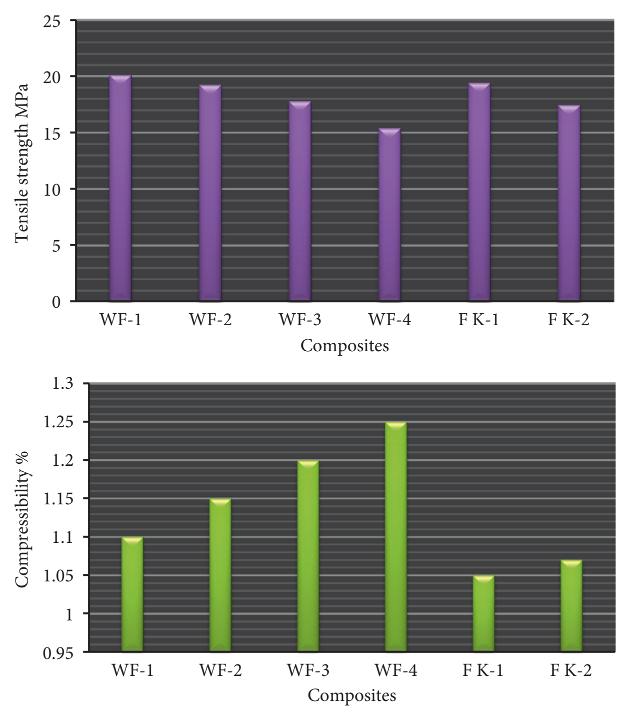

Figure 2: Tensile strength and compressibility of newly developed composites.

PAN fibre composites and also showed minimum strength for WH-1. The Kevlar-based composites showed the highest tensile and shear strength values for FK-1 composites [19]. As the wheat-PAN and Kevlar increase in the matrix, the compressibility increases [20]. Compressibility was highest for WF-4 and FK-2 composites, while it was lowest for 2% wheat straw and Kevlar-based composites, as illustrated in Figure 2 [21]. The inclusion of wheat straw-PAN and Kevlar in the newly created samples increased porosity because wheat-PAN and Kevlar (light wt.) have taken the place of barium sulphate heavy materials [22]. WH-4 and FK-2 have shown maximum heat swelling [23]. Each test has been repeated three times, and average values have been taken. The standard deviation is 0.25 observed during the experiments.

Figure 3 shows the porosity and heat swelling of newly developed composites [24]. The density of wheat-PAN and Kevlar-based composites decreases with an increased percentage in polymer matrix compared to porosity [25]. The porosity and density are directly related to other properties

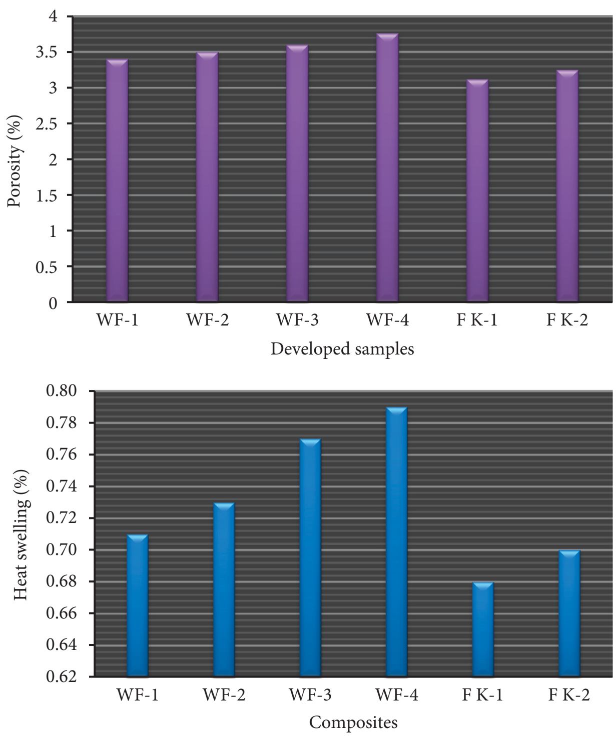

Figure 3: Porosity and heat swelling of newly developed composites.

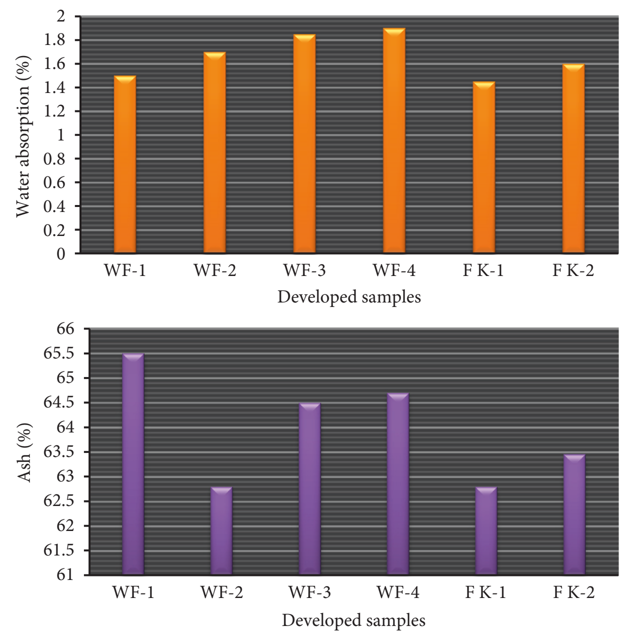

Figure 5: Water absorption and ash percentage of newly developed composites.

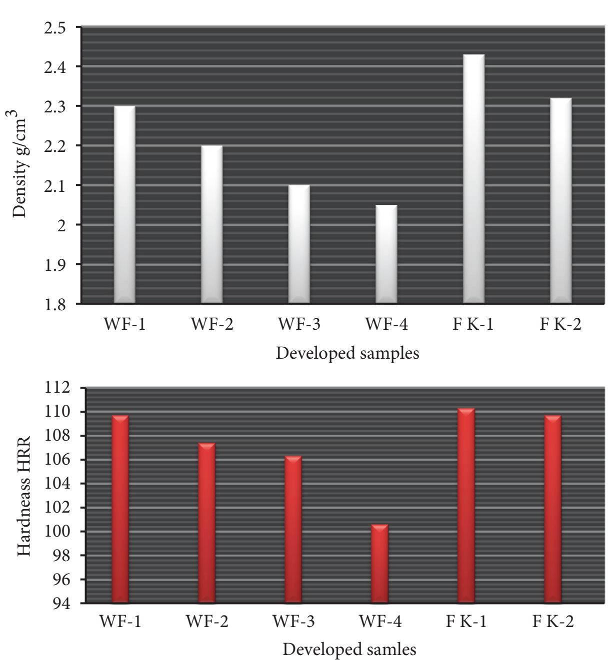

Figure 4: Density and hardness of newly developed composites.

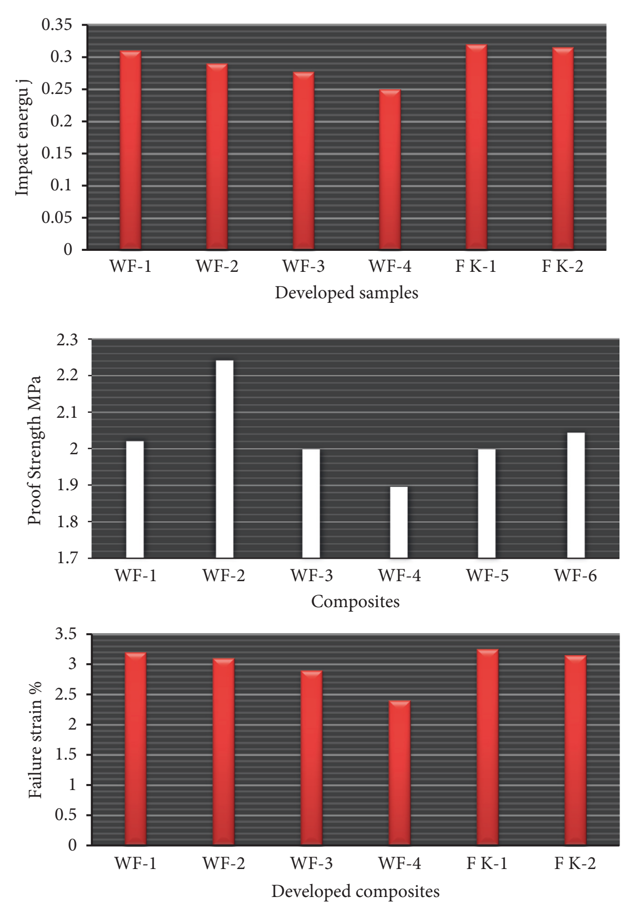

Figure 6: Impact energy and ash proof strength and failure strain of newly developed composites.

like water absorption and compressibility [26]. Figure 4 shows the density and hardness of newly developed composites [27]. At high density and low porosity, the water absorption will be low, compressibility will be low, and opposite to it, low at density and high porosity, the water absorption will be high compressibility [28]. Figure 4 shows

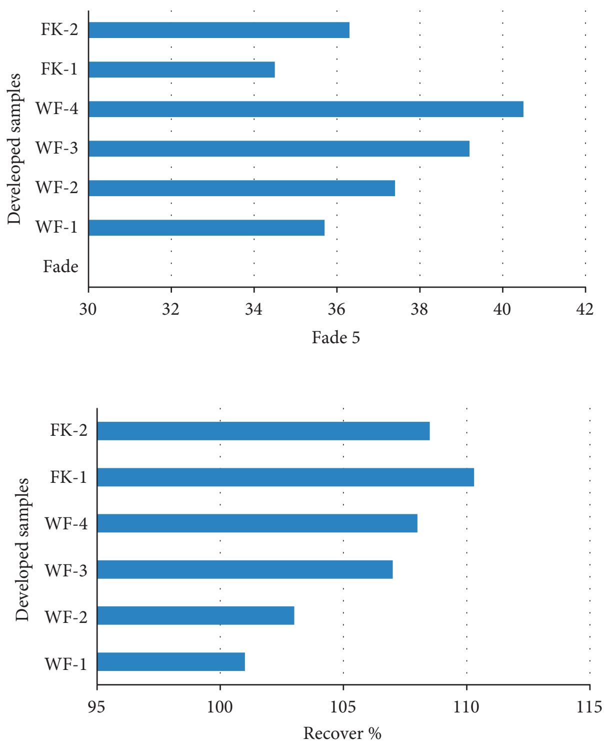

Figure 7: Fade percentage and recovery percentage new developed composites.

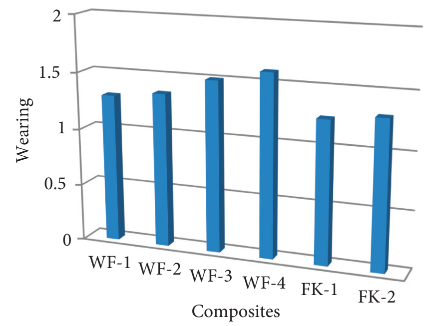

Figure 8: Wear and coefficient of friction behaviour of developed composites.

that hardness was at its highest for WF-1 and FK-1-based composites, while it was at its lowest for WF-4 and FK-2-based specimens [29]. Figure 5 shows that WF-4 and FK-2-based composites have the highest water absorption, while WF-1 and FK-1 composites have better outcomes [30]. The ash percentage was highest for WF-1 and F-1-based composites as shown in Figure 5. Figure 6 shows that the impact energy was highest for WF-1 and FK-1 composites. The failure strain was highest at WF-1 and FK-1 while proof stress was highest at WF-2 and FK-2 as shown in Figure 6 [31].

The fibre's rough surface and morphological properties are important to achieve better interfacial bonding in composites, which decides the composites' load-bearing capacity and performance [32]. They identified the flaky honeycomb and rough surface morphology of *Cissus quadrangularis* root fibre through the scanning electron microscope [33].

3. Tribological Properties

3.1. Fade and Recovery Performance Analysis. The fade percentage of new specimens has increased as increased the percentage of wheat straw fibre-PAN in the new composition (2% = 35.7, 4% = 37.4, 6% = 39.2, and 8% = 40.5), while the increased percentage of Kevlar in the new composition has also increased the fade percentage (2% 34.5 and 4% = 36.3) [34]. As indicated in Figure 7, recovery rose as the percentage of Kevlar (2% = 110.3, 4% = 108.5) and wheat straw fibre (2% = 101%, 4% = 103%, 6% = 107%, and 8% = 108) increased [35]. Organic fibre generates a heterogeneous matrix and shears quickly, acting as third-body particles [36]. This explains why a higher proportion of wheat straw fibre-PAN in the polymer composite causes more fade and wear [37].

3.2. Wear Performance. Figure 8 illustrates the wear range for wheat straw fibre-PAN composites, which is between 1.3 and 1.6 g, while for Kevlar-based polymer composites, it is between 1.25 and 1.3 g [38]. According to the wear test, increasing the proportion of wheat straw fibre-PAN and Kevlar in composites improves the wear rate. The WF-1 composite had the least wear, while the GF-4 composite had the greatest [39]. They made samples with a higher percentage of wheat straw fibre-PAN and Kevlar fibre, which has not shown a homogenous matrix well with the other polymer composite components and causes the wear rate to increase [40]. FK-1 composites are less worn than FK-2 composites.

The triple-layer hybrid composites use almond and kenaf fibres with epoxy resin as a matrix [41]. Two kinds of triple layer composites were fabricated using the hand lay-up method, where fibres are laid in order as kenaf/almond/kenaf and almond/kenaf/almond. Test results show the high tensile (85 MPa) and flexural (92 MPa) properties for the kenaf/almond/kenaf layer composite [42].

3.3. Frictional Stability and Variability Coefficient Behaviour. The stability of the polymer composite deteriorated as the ratio of wheat straw fibre -PAN (2% = 0.82, 4% = 0.8, 6% = 0.76, 8% = 0.73) and Kevlar fibre increased (2% = 0.84, 4% = 0.81) in the new matrix [43]. The WH-1 and FK-1 composites are the most stable of all the composites. The ratio of wheat straw-PAN-based fibre to Kevlar-based composites increased, resulting in increased variability (2% = 0.5, 4% = 0.52, 6% = 0.58, 8% = 0.6) and Kevlar fibre increased (2% = 0.48, and 4% = 0.51). Figure 9 shows that the WF-1, WF-2, and FK-2 proteins have the most consistent and the fewest fluctuations [44].

This flaky rough surface of the fibres contributes to better mechanical properties while making it a composite due to the increased bonding feature of the fibre with the matrix [45]. Moreover, the thermal behaviour of *Cissus quadrangularis* root fibre was studied using Jupiter simultaneous thermo gravimetric analyser (Model STA 449 F3, Netzsch,

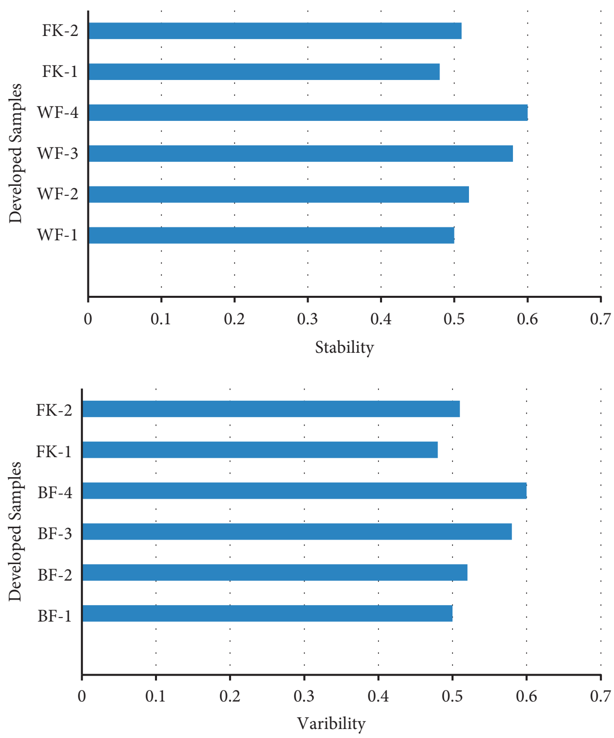

Figure 9: Stability and variability coefficient behaviour of developed composites.

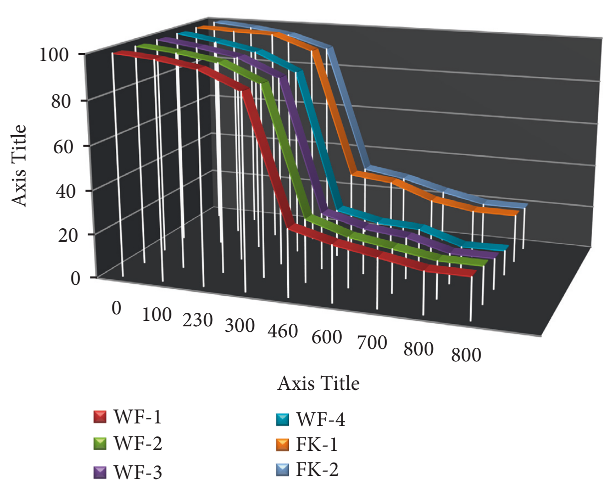

Figure 10: TGA of newly developed composites with variation wheat straw-PAN and kevlar in N_2 atmosphere.

Germany) from 28°C to 1000°C in a nitrogen atmosphere with a 20 ml/min rate of flow and heating at 10°C/min [45].

3.4. TGA of Wheat Straw Fibre-PAN-Based Samples and Kevlar-Based Samples. The TGA test of freshly produced experiments was carried out in a nitrogen [N2] atmosphere, as shown in Figure 10 [46]. The best thermal stability was discovered in WF-4 [47]. In Kevlar-based composites, FK-2 offers better thermal stability in this test. During the test, it was determined that there were three zones of degradation [48]. The first zone showed minimal degradation due to water particles in the composite's significant degradation between 250° and 600°C [49]. In contrast, the second zone showed significant degradation between 250° and 600°C, which could be due to a decrease in hydrogen bonding in Kevlar composites, as well as hemicellulose loss and gas release from wheat straw fiber-PAN composites [50]. The third drop was found in the temperature ranges of 600°C and 800°C. There was relatively minimal degradation in the created samples [51]. The loss of lignin and cellulose from Kevlar and the removal of the amide group. The third degradation is caused by the removal of the amide group and the loss of lignin and cellulose from Kevlar and wheat straw fibre-PAN [52].

4. Conclusions

After all physical-chemical, mechanical, tribological, and thermal testing were completed, the following results were evaluated:

Wheat straw-PAN composites had the best recovery percentage at 8% composition. In contrast, 4% composition of Kevlar-based composites has shown maximum recovery. Composites with 2% wheat waste fibre-PAN and Kevlar-based fibres had the lowest fade percentage. The lowest variability and best stability coefficients were found in all of the newly produced samples (stability). WF-1 (2%) and FK-1 (2%) equals FK-1 (2%) (2%) and FK-1 (2%) composition-based composites were found to have the least amount of heat swelling. In terms of wear, WH-1 (2%) and FK-1 (2%) have shown a minimum wear rate. In composites containing 2% wheat-PAN fibres, water absorption, porosity, and compressibility were found to be low. The composites based on WH-1 were found to have the highest hardness. Shear strength was found to be highest in WF-2 (4%) and FK-1 (2%), while tensile strength was highest in WF-2 (4%). The WF-1 (2%) and FK-1 (2%) composites had the maximum compressive strength and impact energy. Wheat-PAN fiber offers the maximum thermal stability for WH-4. WF-1 has given excellent results in maximum characterization.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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References

[1] J. Cruz and R. Fangueiro, "Surface modification of natural fibers: a review," *Procedia Engineering*, vol. 155, pp. 285–288, 2016.

[2] K. Van de Velde and P. Kiekens, "Thermal degradation of flax: the determination of kinetic parameters with thermogravimetric analysis," *Journal of Applied Polymer Science*, vol. 83, no. 12, pp. 2634–2643, 2002.

[3] T. Singh, N. Kumar, J. S. Grewal, J. S. Grewal, A. Patnaik, and G. Fekete, "Natural fiber reinforced non-asbestos brake friction composites: influence of ramie fiber on physico-mechanical and tribological properties," *Materials Research Express*, vol. 6, Article ID 115701, 2019.

[4] M. A. Maleque and A. Atiqah, "Development and characterization of coir fibre reinforced composite brake friction materials," *Arabian Journal for Science and Engineering*, vol. 38, no. 11, pp. 3191–3199, 2013.

[5] T. Gurunathan, S. Mohanty, and S. K. Nayak, "A review of the recent developments in biocomposites based on natural fibres and their application perspectives," *Composites Part A: Applied Science and Manufacturing*, vol. 77, pp. 1–25, 2015.

[6] R. Yun, P. Filip, and Y. Lu, "Performance and evaluation of eco-friendly brake friction materials," *Tribology International*, vol. 43, no. 11, pp. 2010–2019, 2010.

[7] M. G. Faga, E. Casamassa, V. Iodice, A. Sin, and G. Gautier, "Morphological and structural features affecting the friction properties of carbon materials for brake pads," *Tribology International*, vol. 140, Article ID 105889, 2019.

[8] D. Puglia, J. Biagiotti, and J. M. Kenny, "A review on natural fibre-based composites-part II: application of natural reinforcements in composite materials for automotive industry," *Journal of Natural Fibers*, vol. 1, no. 3, pp. 23–65, 2004.

[9] G. Venugopala Rao, R. Lakshmipathy, G. Ganesh, and N. C. Sarada, "Fourier transform infrared (FTIR) spectroscopy: a superior analytical technique for quantitative estimation of cefditoren pivoxil and its pharmaceutical formulations," *Journal of the Indian Chemical Society*, vol. 91, pp. 179–184, 2014.

[10] V. Andal and G. Buvaneswari, "Preparation of Cu_2O nanocolloid and its application as selective colorimetric sensor for Ag+ ion," *Sensors and Actuators B: Chemical*, vol. 155, no. 2, pp. 653–658, 2011.

[11] K. Hemalatha, C. James, L. Natrayan, and V. Swamynadh, "Analysis of RCC *T*-beam and prestressed concrete box girder bridges super structure under different span conditions," *Materials Today Proceedings*, vol. 37, pp. 1507–1516, 2021.

[12] S. Justin Abraham Baby, S. Suresh Babu, and Y. Devarajan, "Performance study of neat biodiesel-gas fuelled diesel engine," *International Journal of Ambient Energy*, vol. 42, no. 3, pp. 269–273, 2018.

[13] V. Balaji, S. Kaliappan, D. M. Madhuvanesan et al., "Combustion analysis of biodiesel-powered propeller engine for least environmental concerns in aviation industry," *Aircraft Engineering & Aerospace Technology*, vol. 94, no. 5, pp. 760–769, 2022.

[14] G. Koronis, A. Silva, and M. Fontul, "Green composites: a review of adequate materials for automotive applications," *Composites Part B: Engineering*, vol. 44, no. 1, pp. 120–127, 2013.

[15] V. S. Aigbodion, U. Akadike, S. B. Hassan, F. Asuke, and J. O. Agunsoye, "Development of asbestos-free brake pad using bagasse," *Tribology in Industry*, vol. 32, pp. 12–17, 2010.

[16] F. Ahmadijokani, A. Shojaei, M. Arjmand, Y. Alaei, and N. Yan, "Effect of short carbon fiber on thermal, mechanical and tribological behavior of phenolic-based brake friction materials," *Composites Part B: Engineering*, vol. 168, pp. 98–105, 2019.

[17] T. Singh, A. Patnaik, R. Chauhan, and A. Rishiraj, "Assessment of braking performance of lapinus-wollastonite fibre reinforced friction composite materials," *Journal of King Saud University—Engineering Sciences*, vol. 29, no. 2, pp. 183–190, 2017.

[18] M. Kumar and J. Bijwe, "Optimized selection of metallic fillers for best combination of performance properties of friction materials: a comprehensive study," *Wear*, vol. 303, no. 1-2, pp. 569–583, 2013.

[19] N. Aranganathan, V. Mahale, and J. Bijwe, "Effects of aramid fiber concentration on the friction and wear characteristics of non-asbestos organic friction composites using standardized braking tests," *Wear*, vol. 354-355, pp. 69–77, 2016.

[20] S. Kaliappan, M. D. Raj Kamal, S. Mohanamurugan, and P. K. Nagarajan, "Analysis of an innovative connecting rod by using finite element method," *Taga Journal of Graphic Technology*, vol. 14, pp. 1147–1152, 2018.

[21] R. Lakshmipathy, A. V. Vinod, and N. C. Sarada, "Watermelon rind as biosorbent for removal of Cd2+ from aqueous solution: FTIR, EDX, and kinetic studies," *Journal of the Indian Chemical Society*, vol. 90, pp. 1147–1154, 2013.

[22] G. Choubey, Y. Devarajan, W. Huang, L. Yan, H. Babazadeh, and K. Pandey, "Hydrogen fuel in scramjet engines—a brief review," *International Journal of Hydrogen Energy*, vol. 45, no. 33, pp. 16799–16815, 2020.

[23] D. Veeman, M. S. Sai, P. Sureshkumar et al., "Additive manufacturing of biopolymers for tissue engineering and regenerative medicine: an overview, potential applications, advancements, and trends," *International Journal of Polymer Science*, vol. 202120 pages, Article ID 4907027, 2021.

[24] M. Tamilmagan, D. Easu, V. Baskarlal, and V. A Andal, "Synthesis, characterisation, design and study of magneto-rheological property of nano fe_2O_3," *International Journal of ChemTech Research*, vol. 8, no. 5, pp. 65–69, 2015.

[25] S. J. Kim, M. H. Cho, D.-S. Lim, and H. Jang, "Synergistic effects of aramid pulp and potassium titanate whiskers in the automotive friction material," *Wear*, vol. 251, no. 1-12, pp. 1484–1491, 2001.

[26] S.-H. Park, "Types and health hazards of fibrous materials used as asbestos substitutes," *Safety and Health at Work*, vol. 9, no. 3, pp. 360–364, 2018.

[27] D. Jiang, P. An, S. Cui, S. Sun, J. Zhang, and T. Tuo, "Effect of modification methods of wheat straw fibers on water absorbency and mechanical properties of wheat straw fiber cement-based composites," *Advances in Materials Science and Engineering*, vol. 202014 pages, Article ID 5031025, 2020.

[28] J. Dunnigan, D. Nadeau, and D. Paradis, "Cytotoxic effects of aramid fibres on rat pulmonary macrophages: comparison with chrysotile asbestosfibres on rat pulmonary macrophages: comparison with chrysotile asbestos," *Toxicology Letters*, vol. 20, pp. 277–282, 1984.

[29] G. Drummond, R. Bevan, and P. Harrison, "A comparison of the results from intra-pleural and intra-peritoneal studies with those from inhalation and intratracheal tests for the assessment of pulmonary responses to inhalable dusts and fibres," *Regulatory Toxicology and Pharmacology*, vol. 81, pp. 89–105, 2016.

[30] P. J. Isaac, S. Amaravadi, M. S. M. Kamil, K. K. Cheralathan, and R. Lakshmipathy, "Synthesis of zeolite/activated carbon

composite material for the removal of lead (II) and cadmium (II) ions," *Environmental Progress & Sustainable Energy*, vol. 38, Article ID e13246, 2019.

[31] J. Alexander, G. Jayanthi, R. Lakshmipathy, and A. Kulasekaran, "Colour removal studies on treatment of textile dyeing effluent by chitosan modified watermelon rind composite (CWR)," *International Journal of ChemTech Research*, vol. 8, pp. 10–15, 2015.

[32] L. Natrayan, M. Senthil Kumar, and M. Chaudhari, "Optimization of squeeze casting process parameters to investigate the mechanical properties of AA6061/Al_2O_3/SiC hybrid metal matrix composites by taguchi and anova approach," *Advanced Engineering Optimization through Intelligent Techniques*, pp. 393–406, Springer, Singapore, 2020.

[33] Y. Devarajan, G. Choubey, and K. Mehar, "Ignition analysis on neat alcohols and biodiesel blends propelled research compression ignition engine," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 42, no. 23, pp. 2911–2922, 2019.

[34] K. Seeniappan, B. Venkatesan, N. N. Krishnan et al., "A comparative assessment of performance and emission characteristics of a DI diesel engine fuelled with ternary blends of two higher alcohols with lemongrass oil biodiesel and diesel fuel," *Energy & Environment*, vol. 13, Article ID 0958305X2110513, 2021.

[35] P. T. Harrison, L. S. Levy, G. Patrick, G. H. Pigott, and L. L. Smith, "Comparative hazards of chrysotile asbestos and its substitutes: a European perspective," *Environmental Health Perspectives*, vol. 107, no. 8, pp. 607–611, 1999.

[36] G. O. Glória, M. C. A. Teles, A. C. C. Neves et al., "Bending test in epoxy composites reinforced with continuous and aligned PALF fibers," *Journal of Materials Research and Technology*, vol. 6, no. 4, pp. 411–416, 2017.

[37] S. S. Todkar and S. A. Patil, "Review on mechanical properties evaluation of pineapple leaf fibre (PALF) reinforced polymer composites fibre (PALF) reinforced polymer composites," *Composites Part B: Engineering*, vol. 174, Article ID 106927, 2019.

[38] M. J. M. Ridzuan, M. S. Abdul Majid, A. Khasri, E. H. D. Gan, Z. M. Razlan, and S. Syahrullail, "Effect of pineapple leaf (PALF), napier, and hemp fibres as filler on the scratch resistance of epoxy composites fibres as filler on the scratch resistance of epoxy composites," *Journal of Materials Research and Technology*, vol. 8, no. 6, pp. 5384–5395, 2019.

[39] J. Feizy, Z. Es'haghi, and R. Lakshmipathy, "Aflatoxins' clean-up in food samples by graphene oxide—polyvinyl poly pyrrolidone—hollow fiber solid-phase microextraction," *Chromatographia*, vol. 83, no. 3, pp. 385–395, 2020.

[40] V. S. Nadh, C. Krishna, L. Natrayan et al., "Structural behavior of nanocoated oil palm shell as coarse aggregate in lightweight concrete," *Journal of Nanomaterials*, vol. 20217 pages, Article ID 4741296, 2021.

[41] V. Andal and G. Buvaneswari, "Synthesis of Nano CuO by polymeric precursor method and its low temperature reduction to stable copper nanoparticles," *Journal of Nano Research*, vol. 15, 2011.

[42] R. R. Romasanta, B. O. Sander, Y. K. Gaihre et al., "How does burning of rice straw affect CH_4 and N_2O emissions? a comparative experiment of different on-field straw management practices," *Agriculture, Ecosystems & Environment*, vol. 239, pp. 143–153, 2017.

[43] Y. Zhang, G.-Q. Zang, Z.-H. Tang, X.-H. Chen, and Y.-S. Yu, "Burning straw, air pollution, and respiratory infections in China," *American Journal of Infection Control*, vol. 42, no. 7, p. 815, 2014.

[44] A. Korjenic, J. Zach, and J. Hroudova, "The use of insulating materials based on natural fibers in combination with plant facades in building constructions," *Energy and Buildings*, vol. 116, pp. 45–58, 2016.

[45] A. S. Kaliappan, S. Mohanamurugan, and P. K. Nagarajan, "Numerical investigation of sinusoidal and trapezoidal piston profiles for an IC engine," *Journal of Applied Fluid Mechanics*, vol. 13, pp. 287–298, 2020.

[46] Y. Devarajan, B. Nagappan, G. Choubey, S. Vellaiyan, and K. Mehar, "Renewable pathway and twin fueling approach on ignition analysis of a dual-fuelled compression ignition engine," *Energy and Fuels*, vol. 35, no. 12, pp. 9930–9936, 2021.

[47] L. Natrayan and A. Merneedi, "Experimental investigation on wear behaviour of bio-waste reinforced fusion fiber composite laminate under various conditions," *Materials Today Proceedings*, vol. 37, pp. 1486–1490, 2021.

[48] S. Kanniyan, V. Andalgopal, and D. Jose, "A review on nanoparticles based colorimetric detection of toxic ion-chromium," *Journal of International Pharmaceutical research*, vol. 46, no. 5, pp. 453–456, 2019.

[49] R. Lakshmipathy and N. C. Sarada, "Application of watermelon rind as sorbent for removal of nickel and cobalt from aqueous solution," *International Journal of Mineral Processing*, vol. 122, pp. 63–65, 2013.

[50] V. K. Thakur and M. K. Thakur, "Processing and characterization of natural cellulose fibers/thermoset polymer composites," *Carbohydrate Polymers*, vol. 109, pp. 102–117, 2014.

[51] M. Kabir, H. Wang, K. Lau, and F. Cardona, "Chemical treatments on plant-based natural fibre reinforced polymer composites an overview," *Composites Part B: Engineering*, vol. 43, no. 7, pp. 2883–2892, 2012.

[52] V. K. Thakur, A. S. Singha, and M. K. Thakur, "Graft copolymerization of methyl acrylate onto cellulosicbiofibers synthesis, characterization and applications," *Journal of Polymers and the Environment*, vol. 20, no. 1, pp. 164–174, 2012.