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Studies on mechanical, morphological, and water absorption properties of agro residues reinforced polyester hybrid composites

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ABSTRACT

Researchers are increasingly directing their attention toward hybrid fiber laminates, which can be crafted from either natural or synthetic fibers. The Waste to Wealth approach effectively curtails the incineration of paddy straw fibers, reducing air pollution by transforming waste materials into valuable products. In this investigation, paddy straw waste fibers were gathered, and Pine Apple Leaf Fiber (PALF) was extracted using an extraction machine. Alkali treatment was employed to enhance the adhesion properties between the fiber and matrix. Various fiber tests, including the single fiber test, fiber tenacity, fiber fineness, and fiber surface imaging, were conducted to compare the properties of treated and untreated fibers. The reinforcements and matrix were weighed at different percentages using a semi-automatic compression molding machine. The mechanical and morphological behavior of the hybrid fiber-reinforced polyester composites were then assessed. The S9 laminate exhibited a maximum tensile strength of 30.5 MPa, a flexural strength of 47.55 MPa, an impact strength of 108.28 KJ/m^2, a hardness strength of 44 HV, and a shear strength of 41.2 MPa. Fractured specimens' failures were identified through Scanning Electron Microscopy (SEM). The introduction of PALF fiber content (0%, 5%, 10%) resulted in incremental improvements in mechanical strength and a reduction in water absorption properties. Crop residues are completely transformed into innovative products such as tabletops, writing desks, particle boards, and various home applications.

KEYWORDS: Agriculture wastages, polyester resin, characterization, mechanical Properties and microstructure analysis

INTRODUCTION

Several tonnes of agricultural waste were produced throughout the harvesting season. However, minimum percentages of agricultural wastage are utilized for the production of Biogas production, edible fungi, feed, and so on. Most crops are burned and discarded, resulting in negative externality from the waste of resources, environmental pollution, and climate change.

In developing nations, natural fibers emerge as a renewable resource devoid of health risks, offering cost-effectiveness and contributing to pollution reduction through innovative repurposing of waste materials [1-2]. Researchers have identified countable natural fibers in recent years. Characterization and mechanical behaviors of these fiber-reinforced composites have been evaluated [3]. Many authors carried out research works on the part of natural fiber-reinforced composites. Different types of fibers materialized in this world like Jute, hemp, sisal, banana, Kenaf, Coir [4-5], Roselle [6], Flax [7], Luffa [8], etc., The main advantages of NFCs (Natural Fiber Composites) are low density, stiffness, high specific strength, surplus availability, low cost, low environmental impact, lightweight, Biodegradability, etc.; The main disadvantages of NFCs are moisture absorption, Lower strength, lower processing temperatures, etc., [9-13]. To enhance the adhesive bonding between the fibers and matrix, chemical treatments are requisite. [14-16]. Different types of chemical treatments have been used in natural fiber-reinforced composite materials like a silane treatment, alkali treatment, hydrogen peroxide treatment, etc., [17-22]. Natural fiber is often used in lightweight applications as they have a density of 1.2 – 1.6 g/cm^3 which is less than synthetic fiber. It is suitable for manufacturing automobile components (Bonnet shield, engine cover, Bumper, mudguard, and door panel), furniture, construction, frames, shipping pallets, structural applications, and so on [23-27]. Pickering et al. 2016 reported that fiber selection, fiber dispersion, fiber orientation, matrix selection, composite manufacturing process, and interfacial strength are the important factors affecting mechanical characteristics [28]. In the past few years, most researchers focused on hybrid composite materials due to their superior characteristics [29-31]. Different matrices (Epoxy, polyester, vinyl ester, polypropylene, and polyethylene) have been used to fabricate the composites [32-38]. Polyester resin is a less costly and easily available matrix material compared to other matrix materials [39]. Researchers are mostly used to fabricating the composite using the Hand lay-up process and compression molding method with a mold dimension of 300 x 300 x 3mm [40-43].

Abu Shaid (2020) et al. studied the different fiber orientations and fiber stacking sequences in hybrid fiber for the fabrication of composites with the help of a Vacuum-assisted resin infusion process [44].

Ramraji et al. examined the tensile, thermal, and free vibrational properties of composite materials comprising flax fiber interwoven with vinyl ester [45]. Saravanakumar et al. studied the research that explores the transformative capabilities of Musa acuminata fiber-reinforced epoxy composites enriched with alumina particles. The composites were prepared and infused with different alumina particle weight percentages, treated, and untreated Musa acuminata fibers [46]. Ramesh et al. reported using CG fiber-reinforced epoxy composites. This study was imposed on the mechanical properties and thermal behaviors with numerous fiber orientations (0°, 15°, 30°, 45°, 75°, 60°, 90°, 0°/90°, 0°/45°/90°), and the extreme strength exhibited in tensile, flexural and impact as 93.12 MPa, 142.46 MPa, 81.12 KJ/m^2 respectively [47]. Ashok et al. Conducted through ballistic impact testing, water absorption analysis, and morphological observation, the experimental investigation focused on luffa/graphene filler reinforcement within an epoxy matrix. The augmentation of graphene filler in the epoxy matrix enhances both impact and ballistic strength by elevating toughness and hardness values [48]. Sabarinathan

(2021) studied the glass fiber-reinforced recovered brown alumina-filled epoxy composites and found the properties of physical, mechanical, and thermal behavior. The addition of brown alumina filler decreases the tensile strength and increases the hardness and flexural modulus [49]. The results of the investigation done by Hassan et al. revealed that 25% of NaoH-treated rice straw paper has good tensile strength and withstand tearing. The increased percentage of NaOH will decrease the water absorption rate and surface roughness [50]. Natinee et al. (2006) investigated the fiber surface treatments by Pineapple leaf fiber. The 5% NaOH and 1% BPO exhibit the most significant improvement in composite materials characteristics and also improve the thermal aging process [51]. Jayaseelan et al. (2020) reported the weight % of macro particles increases along with the tensile strength. It has been found that a composite with a particle concentration of 35 weight percentage may sustain greater loads, improving its tensile strength and modulus [52]. Farmers and rural communities should be aware of how important waste management is for a sustainable future. Instead of spending money on waste management, conversion of agricultural waste to value-added products [53-54] and fabrication of eco-friendly products from the waste material will help generate wealth from the waste [55]. This not only leads to waste management but also helps in the fabrication of novel and innovative materials with a good strength-to-weight ratio [56] and eco-friendly products that can be used for several applications that those products fit into [57]. Kolahchi et al examined the optimization of dynamic buckling in laminated truncated nanocomposite conical aircraft shells under various temperature and moisture conditions, as well as magnetic fields. The hybrid nanocomposite structural layers are made of carbon nanotubes (CNTs), carbon fibers, and polymers based on the Model Halpin-Tsai. The final equations are solved and deduced using the Mindlin theory. The differential quadrature technique (DQM) and bolotin. The instability and frequency of the structure were taken into consideration in the optimization process using Grey Wolf optimization (GWO), an upgraded metaheuristic algorithm [59-62]. Rahal et al This study centers on preparing a composite material through solid-state reaction methods. Characterization of the samples involved X-ray diffraction, SEM, and TEM analyses. Vickers microhardness measurements were conducted at various loads and dwell times, revealing an inverse relationship between dwell time and Vickers micro hardness. Additionally, the study explored the impact of liquid nitrogen immersion on Vickers microhardness values, indicating a significant enhancement attributed to the increased volume contraction of the superconductor matrix. Various models were employed to analyze the results [63-64]. Unlike synthetic fibers, natural fibers like those from rice and pineapple are biodegradable. This feature is crucial in addressing environmental concerns related to the disposal of plastic products. The composite's end-of-life scenario becomes more environmentally friendly, aligning with the global push for biodegradable materials.

The Paddy straw/Pineapple leaf polyester-based hybrid composites have yet to be reported in any other article. The current research is focused on the utilization of two agricultural wastes (Paddy straw and PALF) in fabricating hybrid natural fiber polyester matrix composites. The influence of the weight percentage of the major amount of paddy straw and the minor amount of Pineapple leaf fiber utilized. The use of natural fibers such as rice and pineapple in polymer composites represents a move towards sustainability. These fibers are renewable resources, and their incorporation reduces the dependence on non-renewable resources, contributing to eco-friendly and sustainable practices. The novelty of the research is stated in the replacement of sawdust and wood dust in the fabrication process of compressed wood products with the hybrid composite material. The use of wood dust in these products is directly or indirectly associated with the deforestation and logging of trees. Deforestation and unsustainable logging practices lead to negative environmental effects (pollution, climate change, respiratory health issues) which can be reduced by replacing agricultural waste and also generating revenue for farmers and rural communities that rely on farming for livelihood. The combination of Oryza Sativa and Ananas comosus fibers may create synergistic effects in the composite material. The interaction between these two types of fibers and the polymer matrix could result in enhanced mechanical properties, providing a composite material with improved strength, stiffness, and toughness compared to traditional polymer composites. The research might explore novel applications for these biocomposites. For instance, the combination of rice and pineapple fibers with a specific polymer matrix might yield a material suitable for unique applications in industries such as packaging, automotive, construction, switchboard, and biomedical fields.

MATERIALS AND METHODS

Extraction of fibers

The Paddy straw fibers were collected from agricultural land. Nowadays, farmers extract paddy using machines. When extracting the paddy using the machine, the paddy stems were broken, which is not suitable for making composite. Hand harvesting paddy straw single fiber test will produce significant results when compared to the machine harvest. After collecting the paddy straw, the unwanted sheath and impurities are removed to obtain the paddy stem. The pineapple leaf fibers were extracted using a double roller fiber extractor machine. Photographic images of the Paddy straw and pine apple extraction process are shown in Figures 1 & and 2.

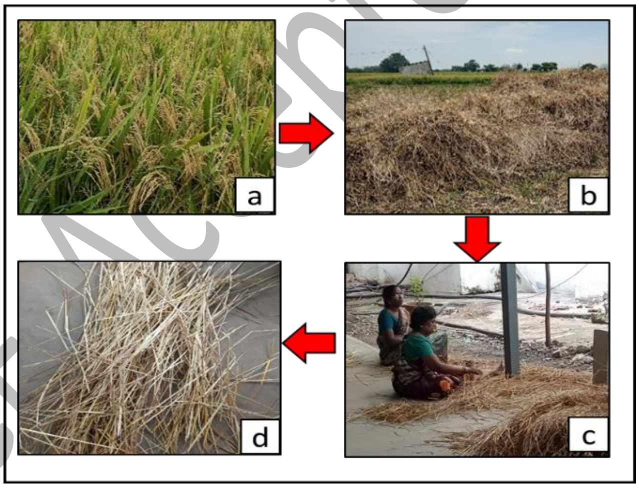


Fig. 1 (a-d): Photographic images of the Agriculture wastage extraction process

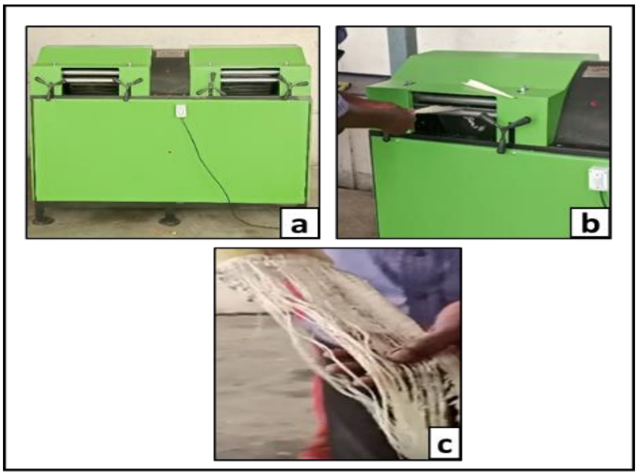


Fig. 2 (a-c): Extraction of PALF Fiber

Alkali treatment of Extracted fibers

Raw fibers, when extracted, are not fabricated directly into laminate due to their inherent limited strength. Some impurities occurred in the Raw fiber surface, such as oil, wax, dirties, etc. Chemical treatments must be used to remove the surface contaminants. It will create a very effective bonding between the fiber and matrix. Good bonding is needed to improve fiber strength. In this study, sodium hydroxide (NaOH) was used with a concentration of 5% for 2 hours [Figure 3]. The concentration of Pineapple leaf fiber is 5%, and its concentration time is 2 Hours shown in Figure 4. Table 1 shows the Chemical composition of fibers.

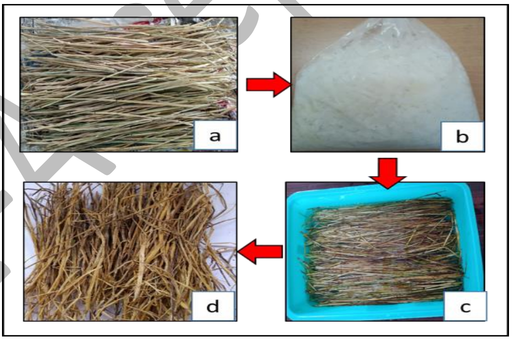


Fig. 3 (a-d): Photographic images of soaked paddy straw fiber

Fig. 4 (a-d): Photographic images of soaked pineapple leaf fiber

Table 1: Chemical composition of fibers

Matrix Properties

In comparison to traditional styrene-acrylate resins, the polyester resin offers greater fusing ability at lower fixing temperatures. It can be sanded, concluding effects in a generally perfect surface. The matrix employed is unsaturated ortho-lamination polyester resin (VBR 2303), necessitating both a catalyst (VBR 1204 - Methyl Ethyl Ketone Peroxide) and an accelerator (VBR 1201 - Cobalt Octoate) [43]. It is used in the ratio of 1.5:1.5 as a matrix material, which is adaptable to the fiber and fabrication Process. Polyester Resin Properties are shown in Table 2. The Schematic image of Methodology is shown in Figure 5.

Table 2: Polyester Resin Properties

Test	**Values**
Density (g/cm^3)	1.132
Viscosity @ 25°C (cp)	470
Volatile content (%)	36.2
Acid value (mg KOH/gm)	25.18
Gel time @ 25°C (Min)	14

Fiber	Density (g/cm^3)	Cellulose (%)	Hemi cellulose (%)	Lignin (%)	Wax (%)	-
Paddy straw (PS)	0.8	28-48	23-28	14	20	Sathiyamurthy et al. 2023
Pine apple leaf fiber (PALF)	1.2	80	0	12	3-5	

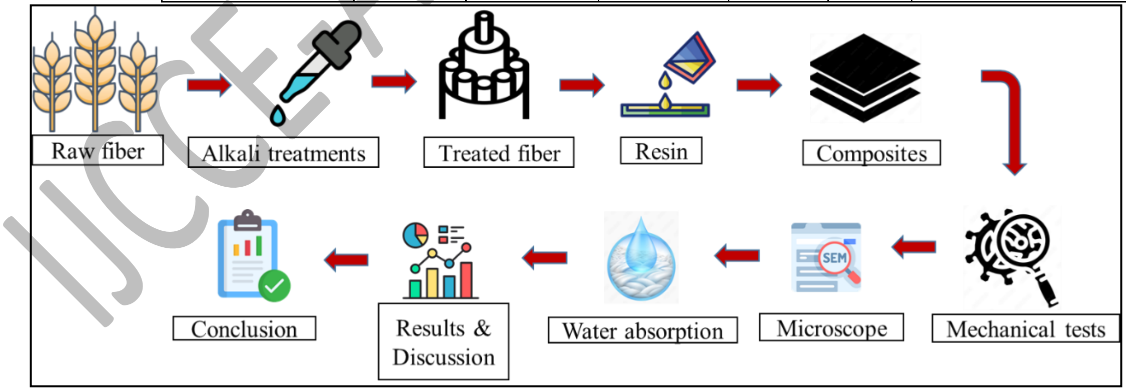


Fig. 5: Schematic image of Methodology

Composite Fabrication

Royal Thermoset Pvt. Ltd makes a semi-automatic hydraulic press molding machine with a capacity of approximately 15 - tons. The unsaturated polyester resin was used with the addition of accelerator and catalyst in the ratio of 1.5:1.5. The fabrication composite's dimension was (300 X 300 X 3) mm with the pressure of 3.5 MPa and temperature 50°C given while fabricating the laminate [18,32,41]. Photographic Image of fabricated composite laminates is shown in Figure 6. The randomly oriented Paddy straw and PALF fiber for different proportions while fabricating the composite laminates are shown in Table 3.

Fig. 6: Image of the composite fabrication (a) Compression molding machine (b) Mould (c) Laminate

Table 3: Different proportions of the Laminate

Classification	**Composite Name**	**Compositions (%)**		
		Polyester	**Paddy straw**	**PALF**
70:30	S1	70	30	0
	S2	70	25	5
	S3	70	20	10
60:40	S4	60	40	0
	S5	60	35	5
	S6	60	30	10
50:50	S7	50	50	0
	S8	50	45	5
	S9	50	40	10

TensileTest

By ASTM standard D638-03, specimens for tensile testing of the manufactured composite laminates were crafted with dimensions of (165 x 19 x 5) mm [46]. The tensile tests were carried out using a UTM - 5-ton machine from Associated Scientific Engg Works, New Delhi. During the test, a gauge length of 100 mm and a constant crosshead speed of 1.5 mm/min were maintained. Five sets of samples were prepared, and the average ultimate tensile strength was recorded. Photographic images of the tensile test machine, before and after specimens are shown in Figures 7 & 8.

Fig. 7: Photographic image of tensile test machine

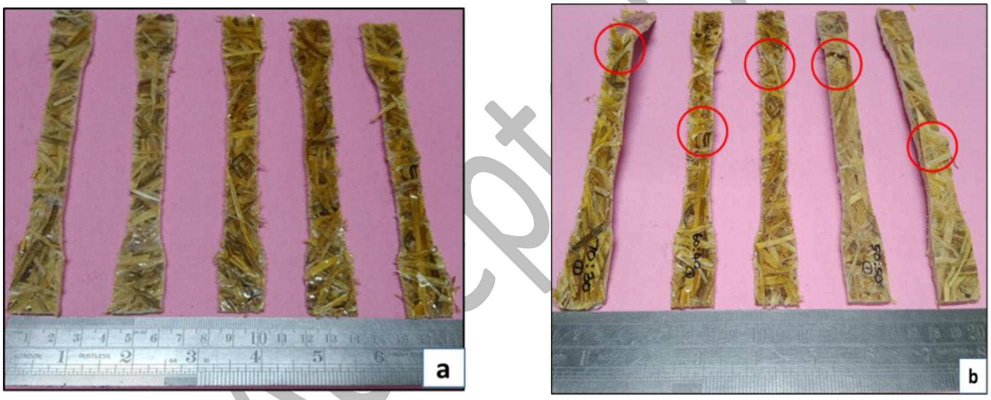


Fig. 8 (a,b): Photographic images of tensile test before and after fractured specimens

Flexural test

In accordance with ASTM standard D790-10, five sets of flexural test specimens were prepared with dimensions of (127x12.7x5) mm. The load was applied at a rate of 5 mm/min, and the specimens were freely mounted on a three-point loader with a span length of 50.8 mm. Photographic images of the flexural test machine, before and after fractured specimens are shown in Figures 9 & 10. The average flexural strength was found by the following equation (1)

$$\sigma = \frac{3pl}{2bt^2} \qquad (1)$$

Where

P – Maximum load; l – Span length; b – width; t – thickness, respectively.

Fig. 9: Photographic image of the flexural test machine

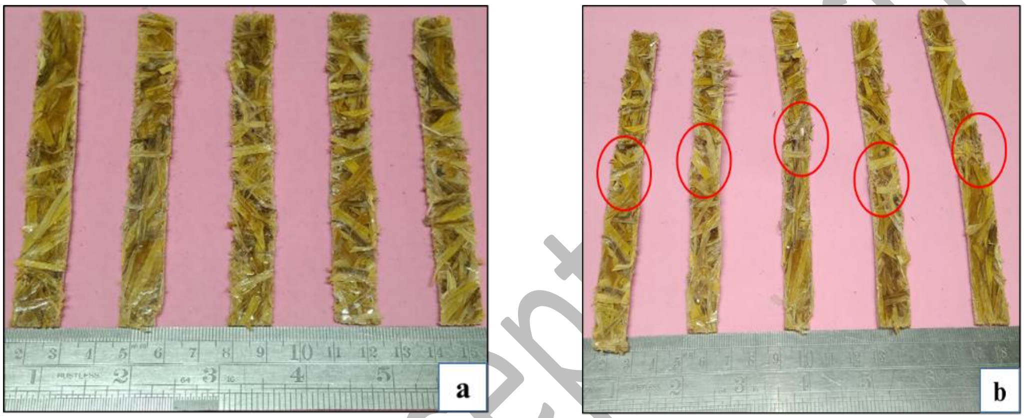


Fig. 10 (a,b): Photographic images of flexural test before and after fractured specimens

Impact test

The impact test was conducted utilizing the XJJU-5.5 model machine, equipped with a pendulum possessing a potential energy of 5.5 J and an impact speed of 3.5 m/s (Izod). Five sets of impact test samples, sized at 65.5 x 12.7 x 5 mm, were prepared in accordance with ASTM D 256-10. The average impact strength values were noted. Photographic images of the impact test machine, before and after fractured specimens are shown in Figures 11 & 12.

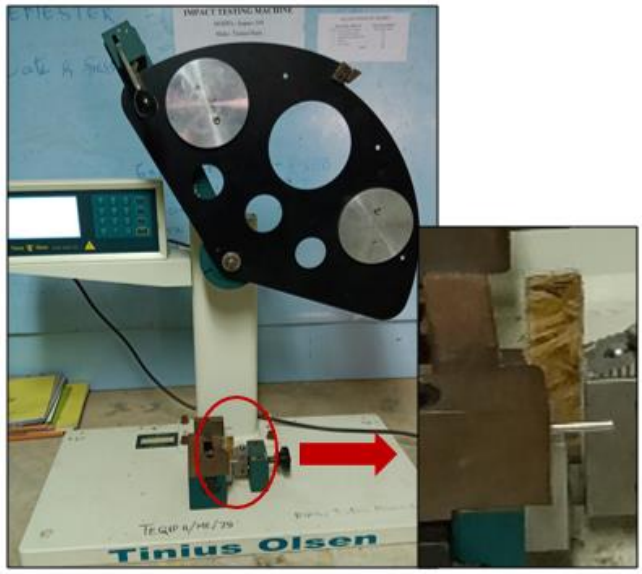


Fig. 11: Photographic image of Impact test machine

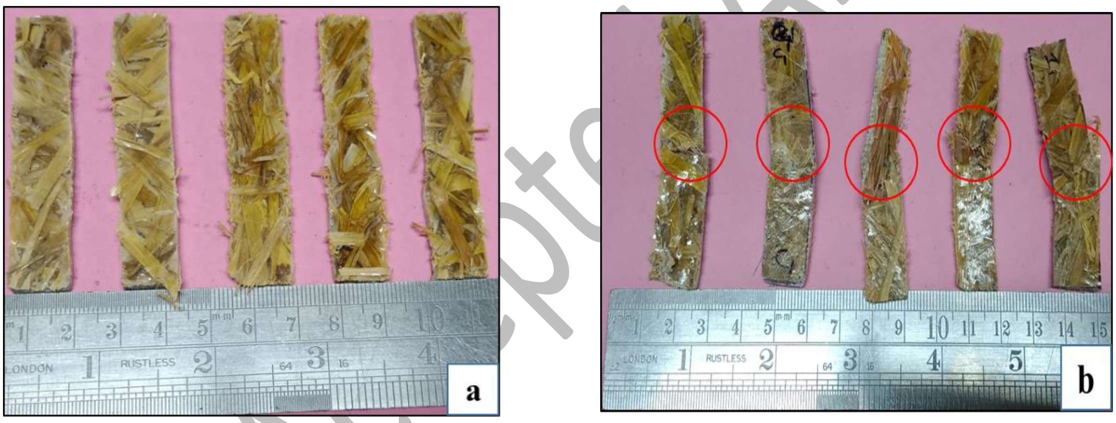


Fig. 12 (a,b): Photographic images of impact test before and after fractured specimens

Hardness test

A vicker hardness tester is used to test the hardness of hybrid composites. HV scale with an indentor of the diamond tool having a diameter of 2.5mm and a load of 0.5 kgf and time 10 secs were used to assess the microhardness. The ASTM E10 standard was followed to prepare samples with the dimensions of 76.2 x 76.2 x 3 mm^3. Hardness values were measured at five different locations within each sample, and the recorded average value was documented.

Shear test

Conforming to ASTM standard D 7617 [43], an in-plane shear strength test (IPSS) was conducted on the diverse types of developed composite materials. The IPSS is determined by the following equation.

$$\text{IPSS} = \frac{\text{Pc max}}{t * h} \qquad (2)$$

Where,

PC max – Ultimate compressive load

h – Distance between the two notches

t – Thickness

Water absorption test

A water absorption test has been conducted for all samples. First, check the weight of each sample and immerse it in normal water for 24 hours. After taking it out, the sample was cleaned with a cloth to remove the water content on the surface and then again weighed. This process is continuously repeated until it reaches the saturation point. The weight gain percentage is as follows,

$$W_g = \frac{W1-W0}{W0} \text{ x } 100 \qquad (3)$$

Where,

Where, W_0 is the initial weight of the specimen.

W_1 is the after weight of the specimen and Wg is the weight gain percentage.

RESULTS AND DISCUSSION

Effects of Alkali Treatment on the Hybrid Fiber

Natural fibers can have their surfaces modified chemically to provide a hydrophobic surface. By removing dirties and impurities structurally to change the fiber surface. Alkali treatment removes some amount of lignin, wax, and oils covering the external surface of the fiber cell wall, depolymerizes cellulose, and exposes the short-length crystallites but does not much affect the crystalline cellulose structure of the natural fiber in the following equations (4) & (5)

$$\textit{Paddy straw} - OH + NaOH \rightarrow \textit{Paddy straw} - O - Na^+ - H_2O + \textit{Impurities} \;\ldots\ldots\; (4)$$

$$PALF - OH + NaOH \rightarrow PALF - O - Na^+ - H_2O + \textit{Impurities} \;\ldots\ldots.\; (5)$$

The breaking of hydrogen bonds in the network structure is caused by the alkaline treatment.

Ramraji et al. The free hydroxyl group (-OH) of natural fiber reacts with sodium hydroxide in the alkaline process, releasing water molecules as well as contaminants such as hemicellulose, wax, and lignin. After the contaminants were removed, it was possible to see that the fiber's surface was uneven, which led to mechanical interlocking with the matrix [12]. Xui Li reported the effects on the alkaline treated fiber (i) It results in enhanced mechanical interlocking by increasing surface roughness. (ii) Increasing the number of possible reaction sites due to an increase in the amount of cellulose exposed on the fiber surface [16].

Effect Single fiber strength in Paddy Straw and PALF

Instron 5500R model machine was used for testing each fiber. While taking the test, the process parameters of Preload – 0.1N, Test speed – 60 mm/min. gauge length 100mm, relative humidity – 65 ± 2%, temperature – 21 ± 1℃ was used. For obtaining a statistical report for each condition, there are 20 fibers from each case used. They are tested to evaluate the average breaking strength, elongation, and fiber tenacity. The raw fiber has more strength than the 5% NaOH treated fiber of both Paddy straw and Pineapple leaf fiber. The untreated paddy straw fiber can withstand the 106N force, whereas the treated fiber can withstand up to 83N force during testing. The untreated Pineapple leaf fiber can withstand the 9.3 N force, whereas the treated fiber can withstand up to 8.8 N force during testing. Single fiber strength and Fiber fineness of Paddy straw and PALF are shown in Table 4.

Table 4: Single fiber strength and Fiber fineness of Paddy straw and PALF

Single fiber strength and elongation (Zwick/Roell)	**Paddy straw (Untreated)**	**Paddy straw (Treated)**	**PALF (Untreated)**	**PALF (Treated)**
Mean Breaking strength F_{max} (gf)	10900 (106N)	8540 (83N)	953 (9.3N)	898 (8.8N)
Mean Breaking Elongation dL at F_{max} (%)	1.2	2.0	8.8	9.6
Tenacity (g/den)	1.14	1.10	3.05	2.75
Fiber Fineness (Denier) Cut & Weigh Method	9558	7758	311.99	326.39

Scanning electronic microscopy / Surface morphology of raw fiber and NaOH-treated fiber

Raw fiber surface has dirties, oil, and wax content. Generally, the alkali treatments will remove the hemicellulose content, oil, wax, and impurities on the fiber surface. After treatment, the fiber has good adhesive properties and will increase the composites' strength. The paddy straw and PALF fiber surface images of raw fiber and treated fiber are shown in Figures 13 & 14.

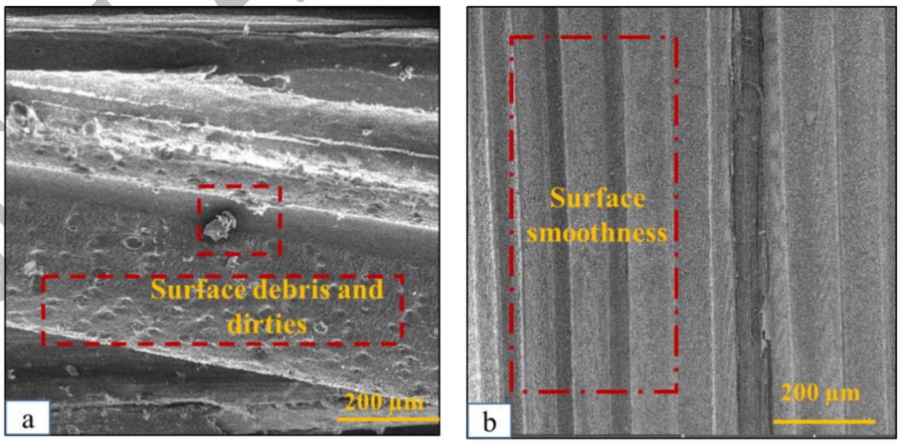
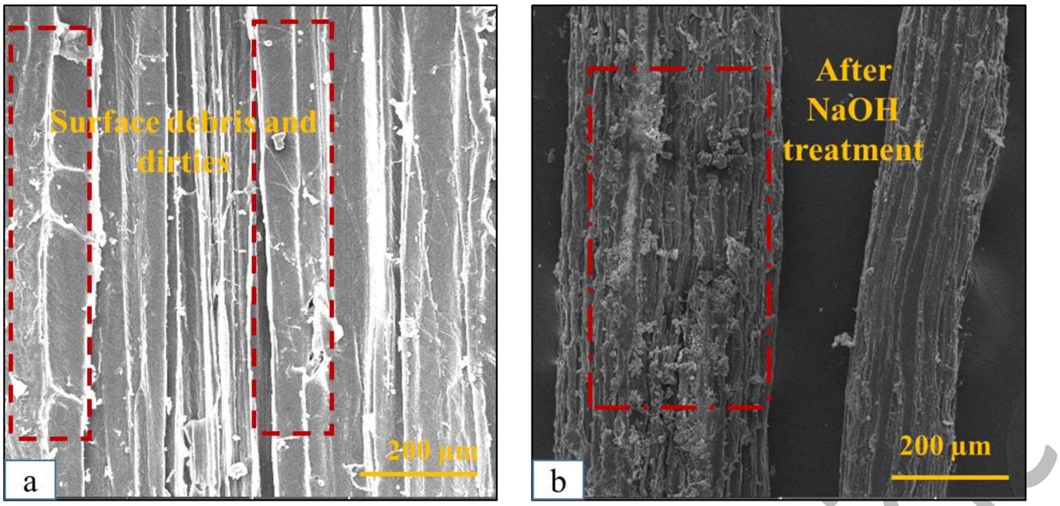


Fig. 13: Paddy straw surface images of before (a) NaOH (b) After NaoH



(a) (b)

Fig. 14: PALF surface images of (a) before NaOH and (b) After NaOH

Tensile Strength

Figure 15 shows variations in the tensile strength for the 70:30, 60:40, and 50:50 (S1 – S9) Sample. The weight percentage modification of polyester and fibers had some effects on the laminates. Hybrid fibers alternatively change the fiber contents and influence the variations in the tensile strength. The results show that the 70:30 ratios (S1-S3) combination achieved the maximum value of 16.3 MPa, whereas the Minimum value of 15 MPa for the S1 Sample. The results revealed that the 60:40 (S4 to S6) combination recorded a maximum value of 28.1 MPa. In contrast, the Minimum value of 17.2 MPa for the S4 Sample and 50:50 (S7 to S9) combination achieved the maximum value of 30.5 MPa, whereas the Minimum value of 21.3 MPa for the S7 Sample. Based on the series, it was detected that the increase in fiber percentage and decrease in resin percentage could raise the strength of the composite laminate. Adding 5 wt % Pine apple leaf fiber in every component modifies the mechanical performance. The S9 Sample with a 50:40:10 wt ratio has the highest tensile strength of the other combinations. When the matrix percentage decreases, the tensile strength gradually increases due to the good bonding between the reinforcement and matrix combination [8]. However, 50:50 hybrid composites show higher tensile strength than the 70:30&60:40.

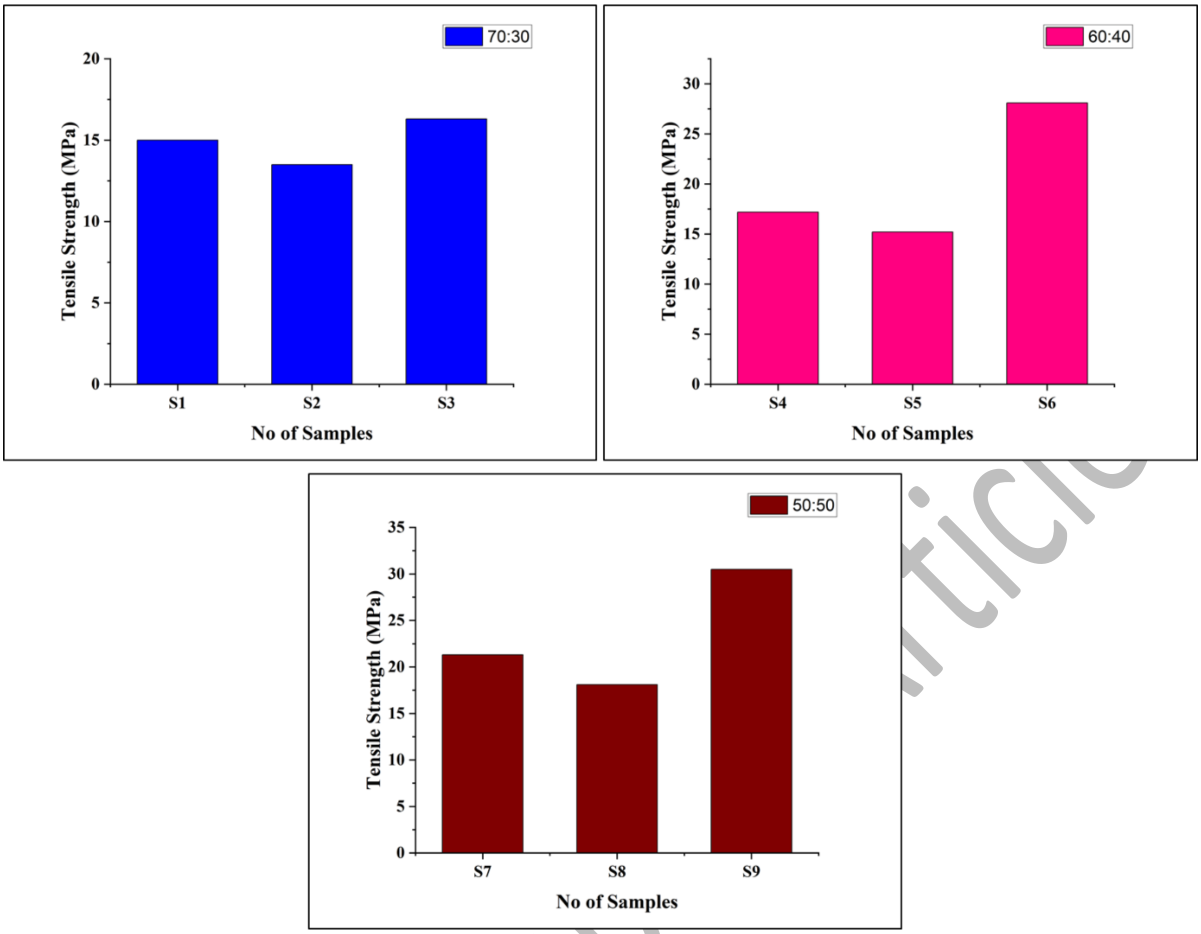


Fig. 15: Tensile strength of PS/PALF Hybrid Composite samples

Micrograph images of tensile-tested specimens

Micrograph inference on the tensile tested sample is shown in Figure 16. Scanning electron microscope helps to find out the fractured surface after failure. Fiber fracture, potholes, fiber splitting, cavity, and broom fracture were observed. The interchange of fibers can serve as an interlock between the matrix and reinforcement, leading to effective interfacial bonding in the composite [48]. From (Fig 16 a) Potholes and cavities showed clearly as there were no fillers added while fabricating the composite laminate and Fiber breakage indicates the addition of load acting on the fiber place. Fig 16 b fiber splitting and brooms-like fracture occurred due to the tensile force heavily acting on the specimen. Fig 16 c clearly indicates that the matrix unfilled area is due to less amount of resin used.

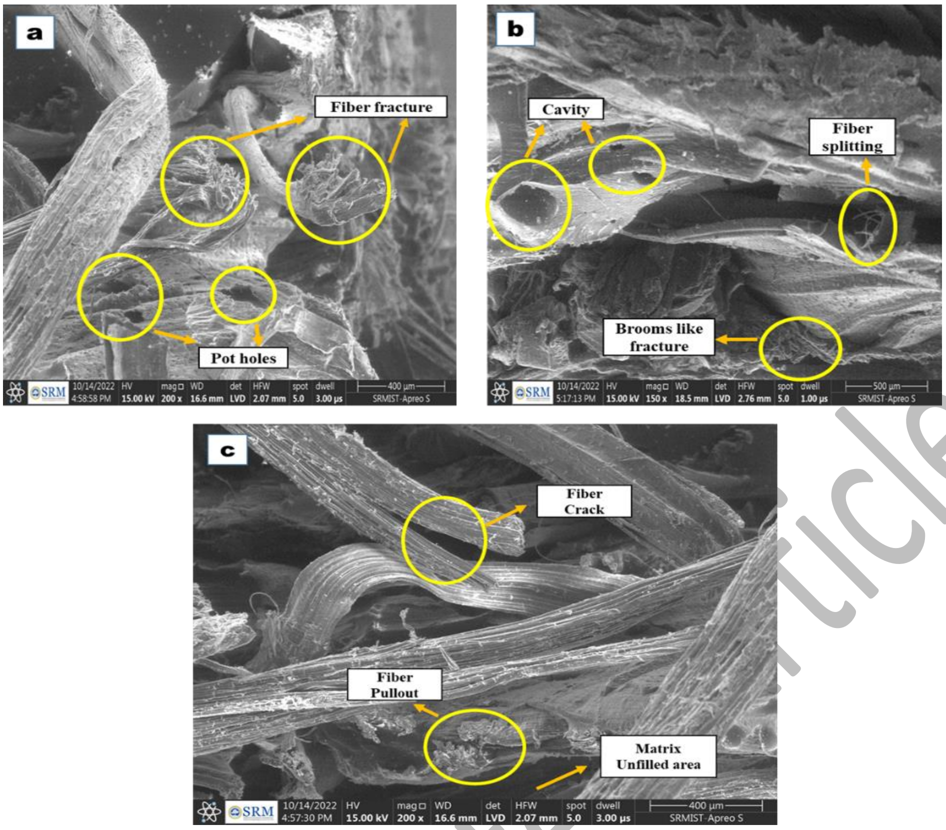


Fig. 16: Micrograph inference on PS/PALF tensile tested sample (a) S3 (b) S6 (c) S9

Flexural strength

Some influences occurred in the composites due to the weight percentage modification of fibers and the resins. Figure 17 shows the variations in the flexural strength of the composite Sample. The results show that the 70:30 (S1-S3) combination exhibited a maximum value flexural strength of 34.7 Mpa and a minimum value of 21.05 MPa for the S1 Sample. The results exhibited that the 60:40 (S4 – S6) combination achieved the maximum value of 41.5 MPa and the minimum value of 32.42 MPa for the S4 Sample, and the 50:50 (S7 – S9) combination achieved the maximum value of 47.55 MPa and the minimum value of 42.25 MPa for S7 Sample. 50:50 combinations, the same equal to the resin and fiber, which achieved the highest flexural strength in all other combinations. The altering the PALF content (0%, 5%, and 10%) the specific flexural strength is differentiated. High specific flexural strength is also a result of the strong bonding between Paddy straw and Pine apple leaf fiber. 50:50 Composites yield a significant enhancement in flexural strength as compared to 70:30 and 60:40.

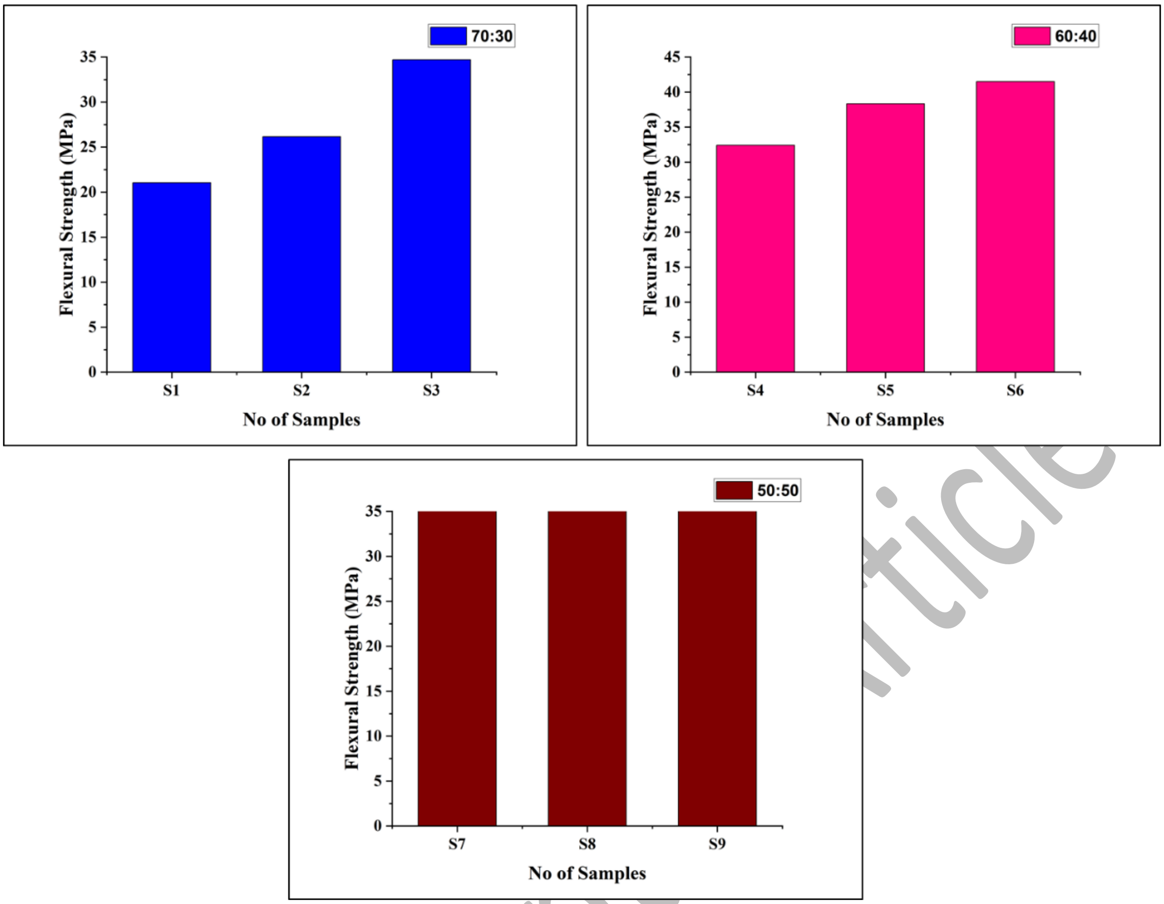


Fig. 17: Flexural strength of PS/PALF Composite samples

Micrograph image of flexural tested specimens

Micrograph inference on the flexural tested sample is shown in Figure 18. A fiber breakage area was observed from the fractured surface due to the flexural load added periodically to the fiber surface. Perfect bonding [48] denotes that stress transfer occurs very effectively from resin to fiber. No fillers were added to this work. Fig 18a micrograph indicates fiber breakage due to periodically added flexural load and failure modes leads to a reduction in the specific flexural strength of hybrid composites [58]. Fig 18b shows the bending of paddy straw and PALF fiber composites micropores, cavity presented. In (Fig 18c) some places have poor bonding and matrix unfilled area in the sample due to 50% resin only being used.

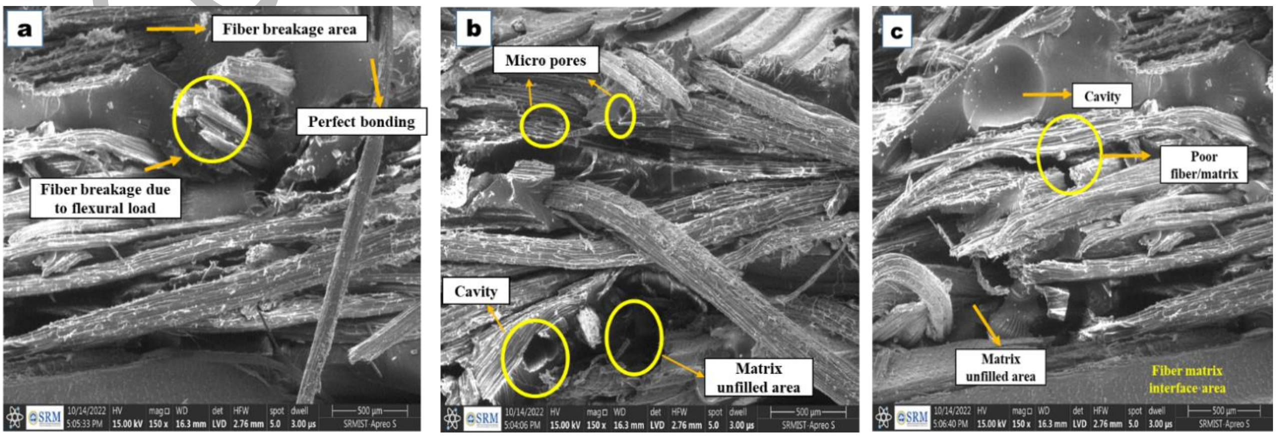


Fig. 18: Micrograph inference on PS/PALF flexural tested sample

(a) S3 (b) S6 (c) S9

Impact strength

The results show that the 70:30 (S1 – S3) combination has achieved the supreme impact strength value of 65.58 KJ/m^2 and the minimum value of impact strength of 39.7 KJ/m^2 for the S1 Sample. The 60:40 (S4 – S6) results revealed that the maximum impact strength value of 87.36 KJ/m^2, whereas the minimum impact strength value of 54.20 KJ/m^2 for the S4 Sample. The results show that the 50:50 (S7 – S9) combination achieved the maximum impact strength value of 108.28 KJ/m^2, whereas the minimum impact strength value of 69.63 KJ/m^2 for the S7 Sample. 50:50 combinations will have the same quantity of resin and fiber, achieving the highest impact strength in all other combinations. Impact strength significantly increases due to a reduction in the matrix and an increase in the reinforcement [4]. It can increase stiffness and hardness because of the heavy interlock between the fiber and matrix. The impact strength of the hybrid composites with altered PALF fibers (0%, 5%, and 10%) showed higher values in Figure 19. Megahed et al observed that particular impact strength is controlled by the interfacial adhesion between the fiber and the matrix [58].

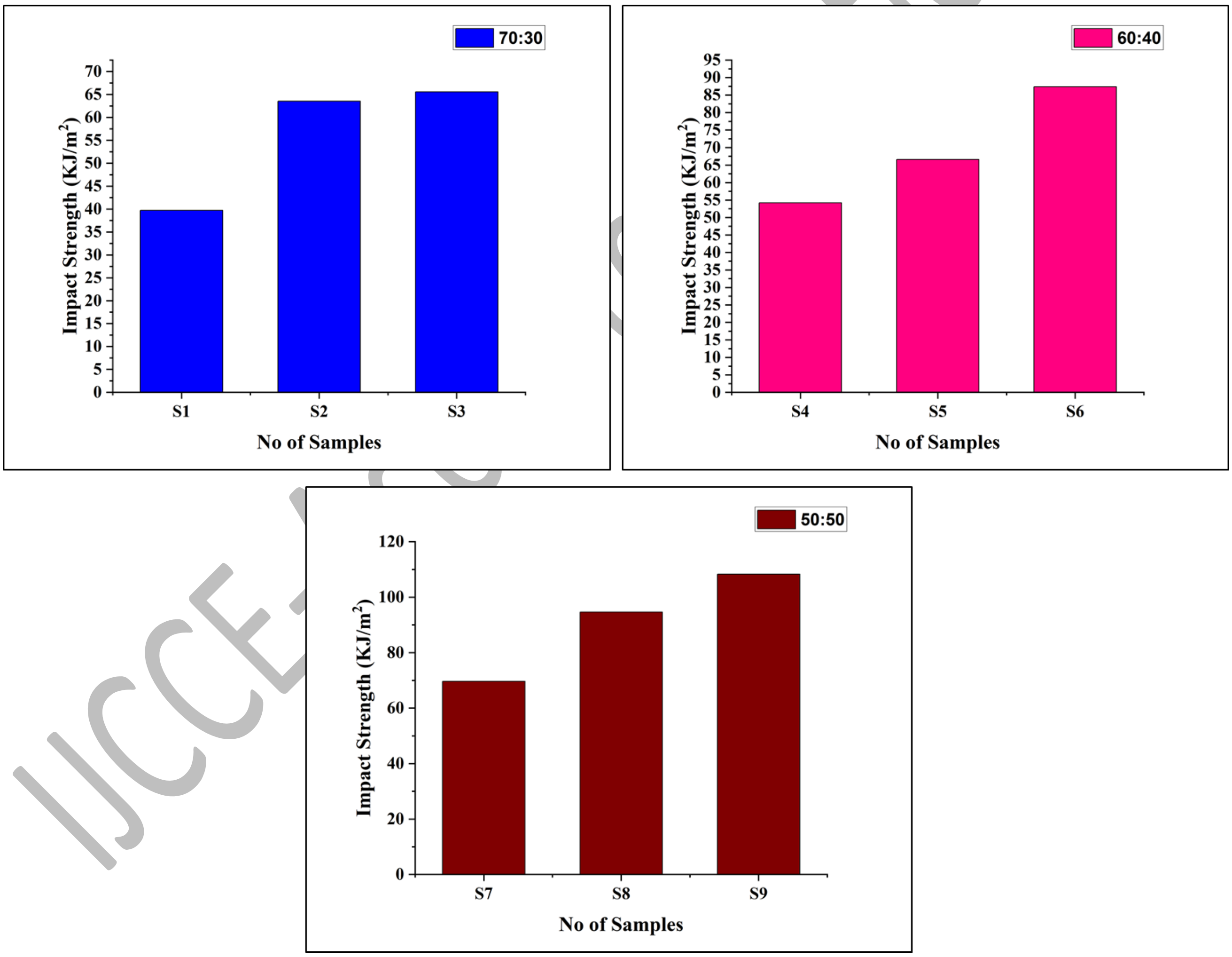


Fig. 19: Impact strength of PS/PALF Composite samples

Micrograph image of impact-tested specimens

Micrograph inference on impact tested sample is shown in Figure 20. It exhibits pothole, fiber fracture, interlaminar shear strength, unfilled matrix area, poor bonding, and Fiber/matrix interface, which were investigated using the scanning electron microscope. Fig 20a shows fractured samples will have a visible presence of potholes, fiber fracture, and interlaminar shear strength in the composite laminate [5]. Figure 20b indicates that Poor bonding of the hybrid fiber denotes the Hydrophobic and hydrophilic nature of the fiber and matrix interface [48]. (c) The image shows that PALF fiber fracture and potholes occurred due to sudden impact load. Due to a lack of resin, the matrix has empty spaces.

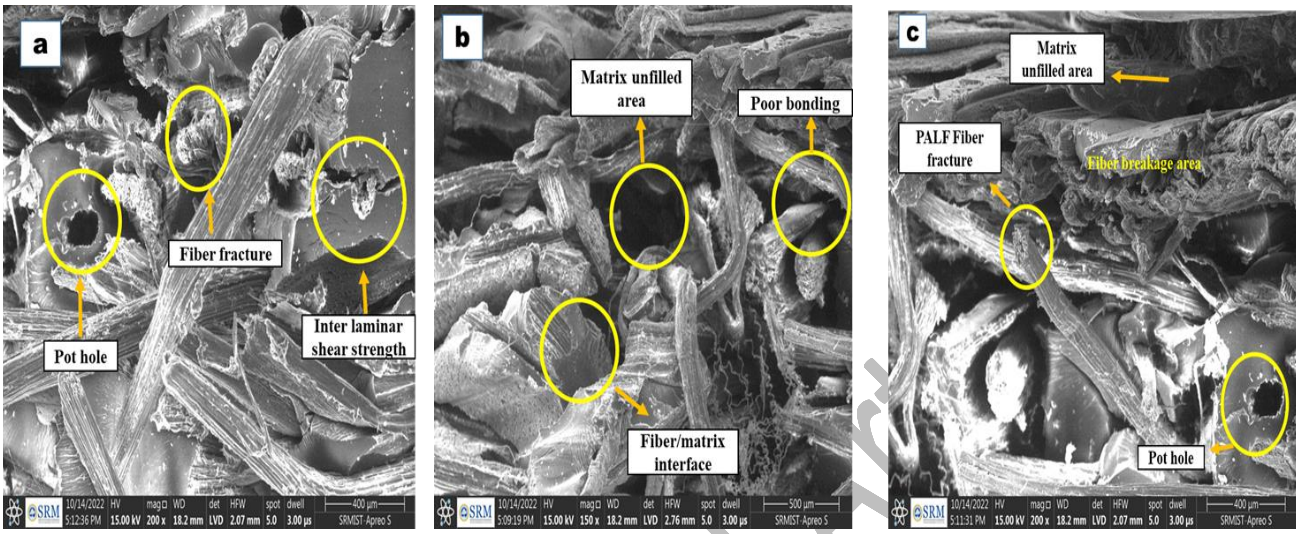


Fig. 20: Micrograph inference on PS/PALF impact tested sample

(a) S3 (b) S6 (c) S9

Hardness test

Figure 21 shows the hardness strength of the composite Sample results. The results show that the 70:30 combinations have achieved the maximum value of 27 HV (S3 sample) and the minimum value of 14 HV for the S1 Sample. The results show that the 60:40 (S4 – S6) combination attained the maximum value of 31 HV. In contrast, the minimum value of 23 HV for the S4 Sample and the 50:50 combination accomplished the maximum value of 44 HV (S9 sample) and the minimum value of 32 HV for the S8 Sample. The S9 specimen attained the highest hardness value compared to the overall samples due to the increase in the stiffness properties of the composite. 10% PALF added hybrid composite laminate (S3, S6, and S9) attributed to the high areal density presented on the laminate due to the reason of an increase in the hardness strength [58].

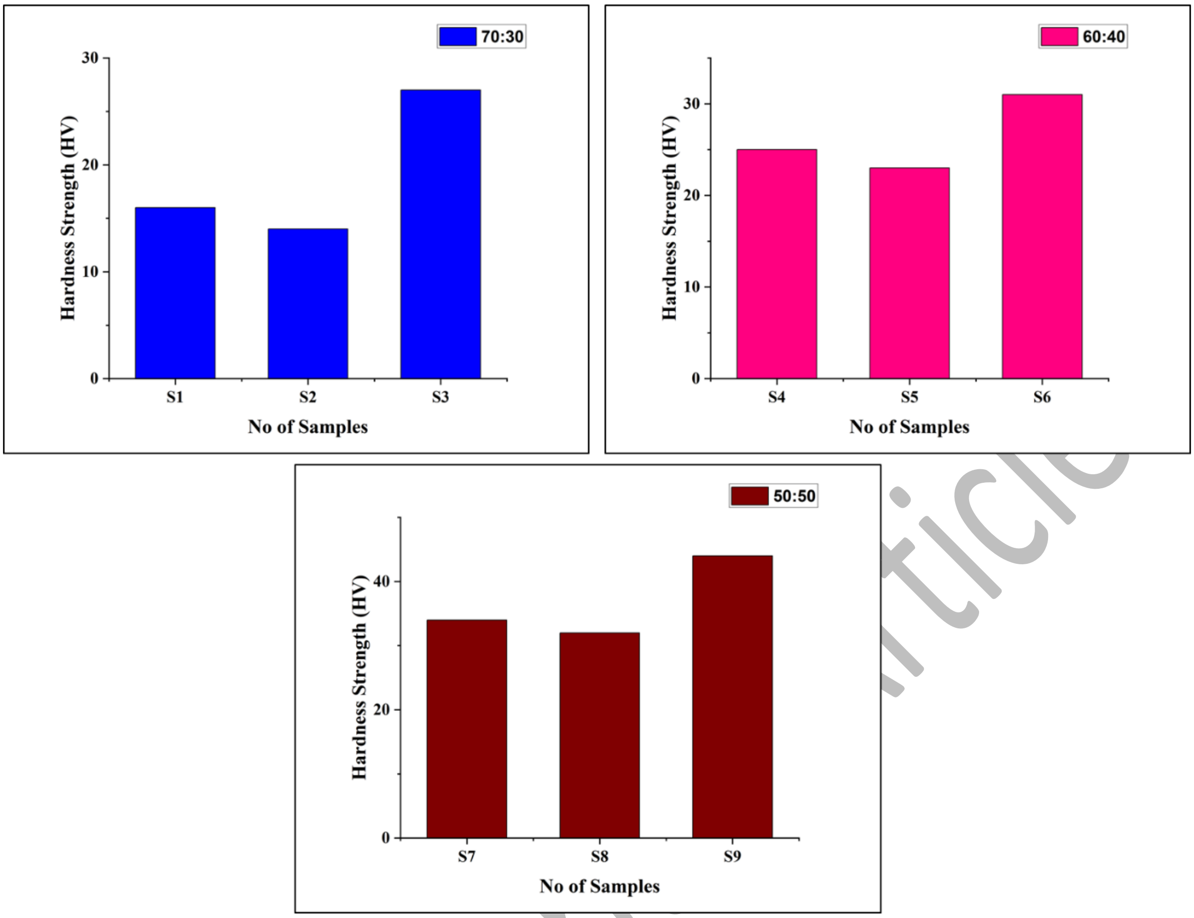


Fig. 21: Hardness strength of PS/PALF composite samples

Shear Strength

Figure 22 appearances the shear strength of the fabricated composites. The shear behavior of the 50:50 (S9) composite value is 41.2 MPa achieved, which is higher than the 70:30 and 60:40. S1, S2, and S3 composites the shear strength values were achieved below 20 MPa only. Increasing the PALF content to major impact on the composite laminate, especially 10% PALF added laminate enhances the highest shear strength value than the 0% and 5%. The shear strength of the hybrid composite is very effective due to the increase in the PALF content and reduction in the resin content. Table 5 shows the overall mechanical properties of the fabricated laminates.

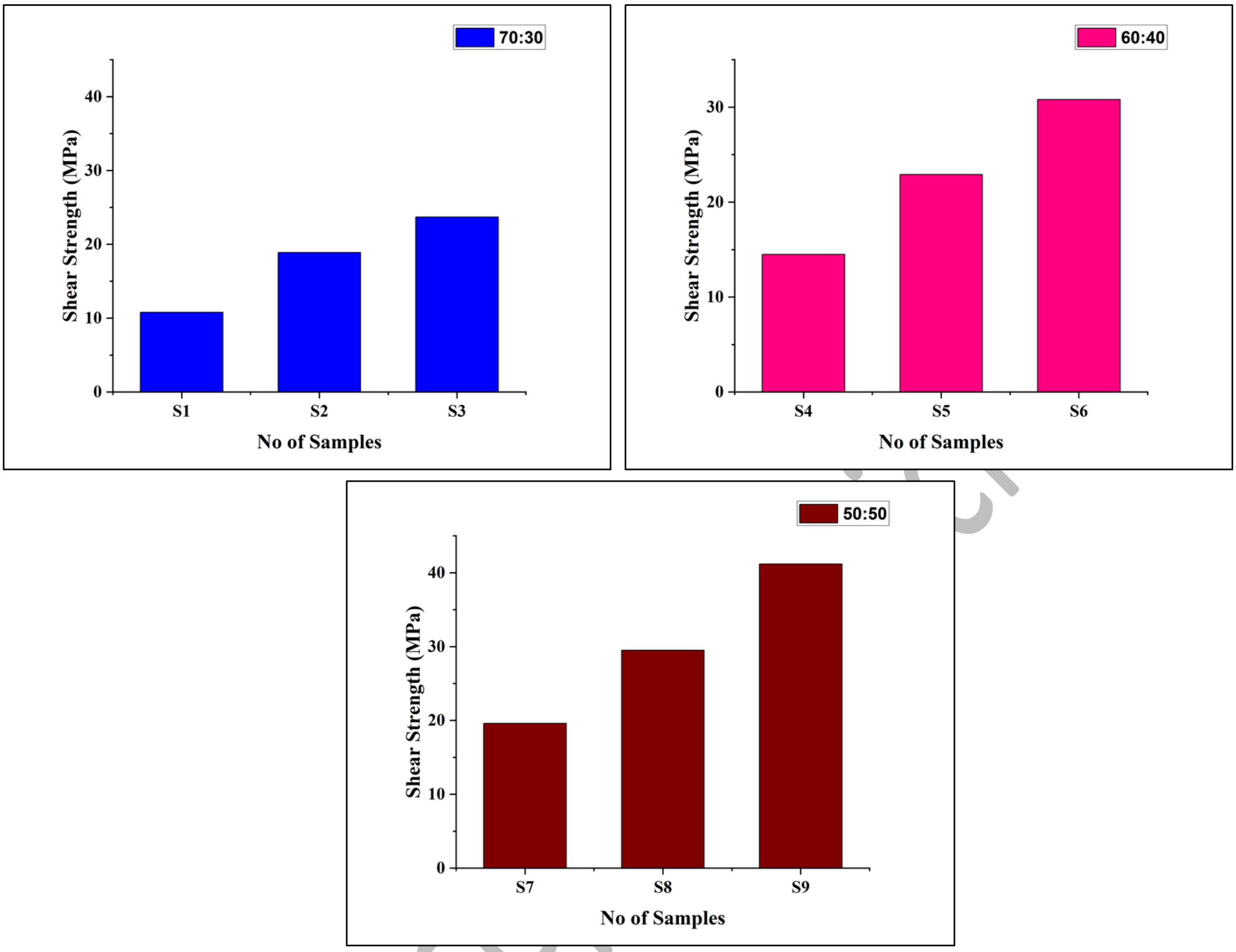


Fig. 22: Shear strength of PS/PALF composite samples

Table 5: Overall mechanical properties of the fabricated laminates

Composite Sample Name	**Fiber/matrix proportion (wt %)**	**Tensile strength (MPa)**	**Flexural strength (MPa)**	**Impact strength (KJ/m^2)**	**Hardness strength (HV)**	**Shear strength (MPa)**
S1	70:30	15	21.05	39.7	16	10.8
S2		13.5	26.15	63.52	14	18.9
S3		16.3	34.7	65.58	27	23.7
S4	60:40	17.2	32.42	54.20	25	14.5
S5		15.2	38.35	66.60	23	22.9
S6		28.1	41.5	87.36	31	30.8

S7	50:50	21.3	42.25	69.63	34	19.6
S8		18.1	43.45	94.63	32	29.5
S9		30.5	47.55	108.28	44	41.2

Water absorption test

The water absorption characteristics of paddy straw can influence its performance in different applications, so the test helps in understanding its behavior under moist conditions.

The water absorption behavior of the sample is shown in Figure 23. The highest water absorption is 48 % (S7 sample). S1, S4, and S7 samples have only paddy straw fiber, which absorbs more water and then slows down after reaching a steady state. Due to the increase in the fiber percentage, the void content of the laminate also increased. Paddy straw fiber is Hydrophilic in nature. The Water absorption results revealed that 70:30 combinations (S1-S3) absorbed more water at 40.65 % (S1 sample), and the minimum amount of water absorption was 25.47 % for S2 Sample. 60:40 combinations (S4-S6) absorbed a greater amount of water, 44.18 % (in the S4 sample), whereas the minimum amount of water was 26.45 % S6 Sample. 50:50 combinations (S7-S9) absorbed a greater amount of water by 48% (S7 sample), whereas the minimum amount of water was 30 % S8 Sample. It is observed that the addition of PALF fiber (5% and 10%) reduces water absorption as compared to paddy straw composite without PALF.

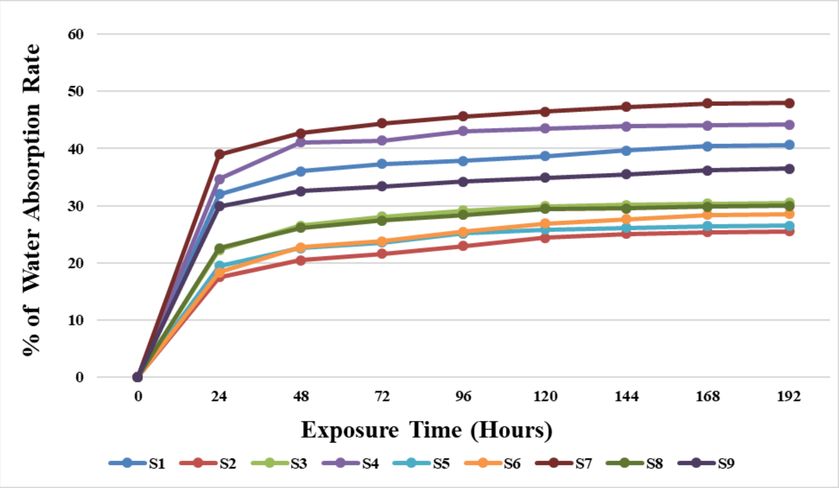


Fig. 23: Water absorption behavior of PS/PALF composite samples

CONCLUSION

In this present research work, we have evaluated the fiber characterization, mechanical, morphological, and water absorption behavior of the polyester composites.

- Paddy straw and both treated and untreated Pine Apple Leaf Fiber (PALF) underwent analysis in the single fiber test, fiber tenacity, and fiber fineness utilizing an Instron model machine. The scanning electron microscope revealed that the surface of alkali-treated fibers is remarkably sleek and efficient.
- It was observed that the combination of 50 wt % resin, 40wt % Paddy straw, and 10wt% PALF offered maximum tensile strength of 30.5 MPa, a flexural strength of 47.55 MPa, Impact strength of 108.28 (KJ/m^2), hardness strength of 44 HV and shear strength of 41.2 MPa in the S9 sample respectively. The

addition of PALF fiber content and minimization of the resin content shows an increase in the mechanical strength of the hybrid fiber-reinforced polyester composites.

- Microscopic images provide insights into the fracture behavior of specimens, revealing features such as potholes, fiber pull-out, voids, fiber splitting, fiber/matrix interface, interfacial bonding, and unfilled areas in the matrix. The augmentation of paddy straw content within the matrix serves as a hindrance to the dissemination of cracks.
- The deforestation and unsustainable logging practices lead to negative environmental effects which can be reduced by the replacement of agricultural waste and generating revenue for farmers.
- Paddy straw fiber is inherently hydrophilic, exhibiting a water absorption behavior in the hybrid fiber-reinforced polyester composite specimen S7, recorded at 39%.
- The paddy straw and pineapple leaf fiber combination often results in composites with superior mechanical properties compared to traditional materials. They can exhibit high strength, stiffness, and impact resistance, making them suitable for various applications.

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