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Effect of Natural Pineapple Leaf Fibre and Glass fibre Reinforced composites with PU Foam Resin using Hand-Layup Process

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ABSTRACT

PU foam-based composites are widely employed in new class of polymer engineering because to their versatility and high demand. Researchers are increasingly focusing on foam for its superior abrasion properties. This study examined how distributing into an PU foam matrix and combining it with pineapple fibres resulted in a hybrid composite with superior mechanical properties. Four layers of pineapple fibre mats were compressed moulded with an PU foam blend to create 5mm thick composites. Curaua was added to . resin at four weight ratios (10%, 20%, 30%, and 40%), resulting in four distinct matrix materials. Pineapple fibre mats were reinforced at a constant weight ratio of 40%. The hybrid composites improved mechanical and abrasion rates, comparable to PU Foam/Pineapple fibre composites being explored as boat frontiers alternatives. The composites morphology was assessed using a Scanning Electron Microscope (SEM). The PU Foam/pineapple fibre composite demonstrated optimal mechanical performance, with tensile strength of 65 MPa, flexural strength of 210MPa, and impact strength of 21 kg/sq. m.

KEYWORDS: *Pineapple leaf fiber,Mechanical Properties, PU Foam Resin,E-glass;*

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I. INTRODUCTION

Recently, there has been an increase in sustainable green technology advances, particularly in the polymer composite business [1]. The present focus is on identifying and characterizing plant fibres for various uses, such as scaffolds for tissue regeneration, medication delivery, and prosthesis design [2-4]. Plant fibres are a viable alternative to synthetic fibres derived from non-renewable sources, such as petroleum (5). Plant fibres are ideal for composite designs due to their abundance, biodegradability, and low density, allowing for high specific strength [6]. Research suggests that pineapple (Ananas comosus) leaf fibres (PALF), a type of agricultural waste, have potential as a polymer reinforcing material [7, 8].PALF contains approximately 80% cellulose, 6-12% hemicellulose, and 5-12% lignin [9,10]. Cellulose, the main component of PALF, comes in two forms: crystalline and amorphous. The crystalline phase contains bundles of microfibrils composed of (1-4) β-D-glucan chains with strong hydrogen bonds [11]. The amorphous phase, made up of randomly distributed cellulose and hemicellulose, has minimal impact on the fiber's structure and mechanical stiffness. Consequently, a number of studies have demonstrated how hydrolysis can remove the amorphous phase, resulting in a greater degree of organised crystalline regions and ultimately increasing the fiber's stiffness [6,12]. Chemical treatment of natural fibres improves both surface morphology and mechanical characteristics [12]. Natural fibres are hydrophilic, making it difficult to connect with hydrophobic matrix's [13].Researchers in the bio-fiber space are exploring treatment techniques to improve fibre matrix bonding for composite reinforcement applications [14], as well as the effect of alkali on mechanical, degradation, and water uptake properties of PALF reinforced composites [15], and the production of nanocellulose from PALF [16]. Fibre stiffness varies based on treatment procedures and chemical concentrations [12]. Few studies have been conducted on the use of 6% NaOH for fibre treatment, resulting in limited mechanical properties for PALF under this treatment. However, the crystallographic information after %

NaOH treatment has not been fully characterised. The authors aim to provide insights into the mechanical and crystallographic properties of PALF after different alkaline treatments. This work provides insight into how increased alkali treatment of PALF affects its mechanical properties, despite increasing crystallinity and crystallite size.

II. LITERATURE REVIEW

Natural fibre reinforced .-based polymers are a valuable resource for developing wear-resistant brake pads. This experiment combines U and . to improve mechanical and wear qualities, taking advantage of PU foam's excellent friction resistance. . is commonly used in the engineering industry due to its ease of application, low cost, limited shrinkage while curing, and superior mechanical qualities compared to other thermoset polymers [1]. Adding natural fibres to . composites improves mechanical strength while maintaining weight and durability [2]. Pineapple leaf fibres are among the toughest natural plant fibres. In India, these materials are affordable and have a high tensile strength [3]. According to a literature review, pineapple fibres are roughly ten times stronger than cotton fibres and contain a high cellulose concentration (56% - 68%), exhibiting their inherent mechanical properties [4]. Pineapple leaves contain 12% lignin, which makes them fibrous and hard. Reinforced polymers have increased mechanical properties. Pineapple leaf fibres are commonly used in ropes and bags, but they can also be woven with polyester for use in the textile industry. Fire and wear resistance qualities [7]. PU foams are layered silicates with non-metric diameters of 50-200 nm. Montmorillonite (MMT) is the most widely used industrial grade of PU foams due to its ease of availability, cost-effectiveness, and processing capabilities [8]. MMT consists of phyllosilicate sheets organised at a 2:1 ratio, resulting in two variants: Cloisite 30B and Cloisite 20A. Cloisite 20A is less expensive and more widely available than the earlier. Organically modified Montmorillonite (OMMT) has antibacterial properties that resist bacteria and fungi [9]. This component indirectly protects natural fibres (like pineapple fibres) from bacterial and fungal attacks. PU foam's high surface area and reactivity allow for robust interactions with resin-based polymers. Research suggests that . resin with a PU foam content of 1-8 wt% has superior mechanical, thermal, and tribological qualities [10]. Recent investigations [11] have employed .-infused PU foam at 4 and 5wt% as a matrix material. In another investigation, . and polyester matrices were reinforced with PU foam at 5% and 10% respectively.At 5 and 10 wt%, ./PU foam composites outperformed polyester/PU foam composites in terms of mechanical properties [12]. Adding up to 2 parts per hundred resin (phr) of PU foam to an . matrix improves mechanical and thermal properties [13]. Sudhagar et al. [14] used incremental PU foam reinforcement in . resin with weight percentages of 2, 4, 6, and 8%. The 4 wt% reinforced PU foam . composite demonstrated the highest ultimate tensile strength, young's modulus, flexural properties, and microhardness. Adding more than 4 wt% PU foam to composites reduced their strength.Kumar et al. [15] created . composites with PU foam weight reinforcements of 3, 5, 7, and 10%. This study found that adding PU foam up to 5 wt% to composites improved mechanical properties, as described in previous research. Beyond 5 wt%, the strength and other physical attributes of the final composite were reduced. Hybrid polymer composites can be used effectively in industrial applications with mechanical and frictional shear forces for sliding. They can withstand mechanical stress and have great stiffness, resulting in good wear resistance. Hybrids outperform plain polymers and monomaterial reinforced polymer composites in terms of mechanical strength [10, 14]. Reducing shear rate in mechanical materials for frictional applications is crucial for long-term performance and service life [16-17]. This study combines pineapple leaf fibre and PU foam-infused . resin to create a hybrid composite with high abrasion resistance for brake pads and sports items.

III. MATERIALS & PROCEDURE

A. MATERIALS

The base resin used was Diglycidyl Ether Bisphenol-A (DGEBA) . grade LY556, which has a density of 1.16 g/cm^3 and an 8-hour cure time at 140°C. The hardener used was Triethylenetetramine Hardener (HY951) with a density of 0.95 g/cm^3. The materials were purchased from CIPET in Chennai, India. Go Green Products in Chennai, India, provided a 1 mm thick pineapple (Ananas Comosus) leaf fibre mat in fabric form. The fibre diameter and density measured by the supplier were 180 microns and 1.543 g/cm^3, respectively. Cloisite 20A MMT. Ultrananotech Pvt. Ltd, Bangalore, India, provided dry powder PU foam with a density of 1.7 g/cm^3 and sieved through #500 mesh.

B. FABRICATION METHOD

The basic solution was created by combining . resin and hardener in a 10:1 ratio. utilising this basic solution, a plain . slab was created utilising compression moulding techniques. To create a composite laminate slab with a standard thickness of 4 mm, four layers of natural pineapple leaf fibre mat were hand-layed with the base . solution and compressed at 180^{o}C under 1000 N pressure for 4 hours. The handlay-up method was used to create four layers of Pineapple mat fibre (P) and Base . resin (E) in the following sequence: E/P/E/P/E/P/E/P/E. The laminated Pineapple leaf fibre . composite slab cured for 48 hours at room temperature after processing. The .

polymer and fibre reinforced composite slabs were cut to ASTM standard dimensions test specimens using Water Jet Machining (WJM) and coded as 'E' and 'EP', respectively.To prepare the PU foam-based hybrid composite, it was dehydrated at 90°C in an induction furnace for 5 hours to remove all moisture. This step will guarantee better bonding throughout the mixing phase. The Base . resin was heated to 80°C to reduce its viscosity [13]. Using a lower viscosity . allows for more uniform dispersion of PU foam throughout the resin. There was no clogging, and the solution was smooth. To improve dispersion during ultrasonication, a 1:10 curing reagent was added to the . and PU foam combination. To create unique ./PU foam solutions, the matrix material was processed using different PU foam reinforcement ratios (2, 4, 6, and 8 wt%). To create hybrid composites, PU foam reinforced . resins were used as matrix materials, with the same processing parameters as plain . polymer and natural fibre reinforced composites.The hybrid composite slabs were cut into test specimens using WJM after an initial hand-layup process, followed by compression moulding. Test specimens were constructed to ASTM dimensional standards for mechanical characterization, including ASTM D628 for tensile, D790 for flexural, and D256 for impact tests [19-20].Table 1 shows the codes assigned to the hybrid composite specimens: EPN1, EPN2, EPN3, and EPN4.

Table 1: Test Specimen Constituents and Their Codes

Specimen Code	Resin Base PU Foam (wt%)	Pineapple Fibre (wt%)	E-glass Content (wt%)
E	100	0	0
EP	75	25	0
EPN1	73	25	2
EPN2	71	25	4
EPN3	69	25	6
EPN4	67	25	8

C.EXPERIMENTATION PROCEDURE

A Universal Testing Machine (UTM) (Model: INSTRON-3365) was used to test elasticity and bending behavior of the test specimens. Tensile test was performed to ASTM D628 and three point flexural test was performed to ASTM D790 by alternative arrangements of fixtures respectively for the test procedures. A standard and constant force of 10 kN and a head movement speed of 2 mm/min was applied for both the tensile and flexural tests until the test specimens underwent catastrophic failure. For testing the toughness of the specimens, Izod impact test was performed to ASTM D256 with hammer head force of 25 Joules[21].

IV. RESULTS & DISCUSSION

A. TENSILE STRENGTH

The tensile strength values of the tested specimens. Reinforcing pineapple leaf fibre with . resulted in a 59.33% increase in tensile strength, with the EP composite reaching 136.87 MPa compared to 55.66 MPa for plain E. The use of pineapple fibre as a load-bearing agent improved the tensile strength of the . material [22]. The inclusion of PU foam at 2 wt% increased the tensile strength of EP composite from 136.87 MPa to 153.6 MPa. Increasing PU foam content increased the tensile strength to 166.75 MPa. Figure 1 shows that when the PU foam load exceeded 4 wt%, the tensile strength of the EPN3 and EPN4 composites gradually decreased. The EPN2 composite outperformed all other test specimens in terms of tensile strength, increasing by 66.62% over plain . and 17.91% above EP composite. The PU foam reinforcement improved the matrix's bonding ability with pineapple fibre, surpassing that of the base . resin. The test specimens in this study showed identical tensile modulus values to their tensile strength results. Adding pineapple natural fibre and PU foam improved the base .'s tensile modulus by 70.90% and 40.67%, respectively, compared to 'E' and 'EP'. The addition of PU foam above 4 wt% resulted in decreased modulus values. Higher PU foam content in EPN3 and EPN4 composites caused particulate agglomeration, resulting in stress residues and faster fracture during testing compared to the optimum loading of PU foam content in EPN2. After reinforcement with pineapple fibre, the flexural strength of E increased by 26.31% to 458.86 MPa from 338.1 MPa. Adding PU foam matrix to pineapple fibre enhanced flexural strength to 755.23 MPa. PU foam particles sank into the interspatial voids between fibre matting, increasing flexural strength and boosting matrix-fiber adhesion.

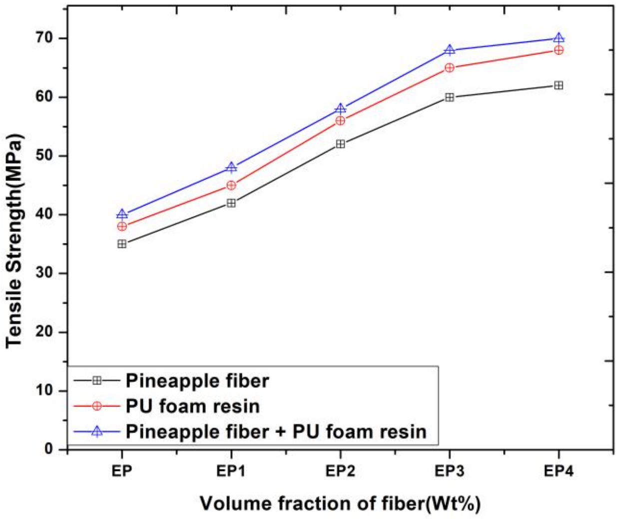

Fig.1 Tensile strength versus volume fraction of fiber

Flexural strength increased up to 4 wt% PU foam concentration, after which it decreased. Overloading PU foam reinforcement resulted in agglomeration and weaker adhesion between the matrix and fibres. The EPN2 composite outperformed Base,EP composite, and EPN3 Hybrid in terms of flexural modulus, increasing by 58.3%, 37.79%, and 22.14% respectively. The increased flexural modulus of PU foam-reinforced hybrid composites can be attributed to the increased surface area provided by the PU foam particles, resulting in better adhesion with the . resin [11, 23]. This factor increased the stiffness of hybrid composites. The hybrid composite's characteristics decreased at 6 and 8 wt% PU foam reinforcement due to agglomeration caused by the . resin's inability to wet the large PU foam quantity evenly [12, 18]. The presence of agglomerated PU foam particles caused weak areas in specimens during testing, resulting in abrupt cracks and faster fracture of EPN3 and EPN4 specimens compared to EPN2 [23]. In an impact test, PU foam reinforced hybrid composites outperformed the base . specimen 'E' and the Pineapple fibre reinforced . specimen 'EP'. Figure 5 demonstrates that the EPN2 specimen outperformed all other test specimens in terms of impact strength. The impact strength of 'E' was 52.51, while reinforcement with natural fibre (specimen 'EP') resulted in an impact strength of 90.67. Natural fibres distributed impact loads evenly throughout the specimen, while plain polymers were more brittle and prone to breaking and failure. Adding PU foam to the 'EP' material significantly improves impact resistance. The EPN2 composite with 4 wt% PU foam content had the maximum impact strength. The impact strength increased by 23.47% compared to EPN1. EPN2 outperformed other materials in terms of impact resistance due to its uniform distribution of PU foam and fibril gaps (18, 24). Adding 6 wt% and 8 wt% PU foam to EPN3 and EPN4 composites resulted in a 20.18 and 25.82% reduction in impact strength. Higher PU foam [25] content caused congestion and uneven distribution within the matrix material, resulting in blind areas and faster fracture under impact stress compared to EPN2.

B. FLEXURAL STRENGTH

Figure 2 displays the abrasion rate of all test specimens during the abrasion test, based on the amount of material removed owing to shear. The plain . specimen 'E' had the highest abrasion rate. The addition of pineapple fibre lowered the abrasion rate of the 'E' from 0.198 g/m to 0.1738 g/m for the 'EP' composite. Natural fibres contain varying chemical compositions, including cellulose, hemicellulose, and lignin [26]. Pineapple fiber's high cellulose content improved the composite's ability to sustain shear stress during testing, outperforming base . 'E'.Adding PU foam lowered the abrasion rate of 'EPN1' to 0.1569 g/m. Increasing PU foam content reduced the composite's abrasion rate [10]. EPN4 had the lowest abrasion rate among all test specimens in the research study. PU foam's natural capacity to sustain strong shear forces [12] supports the findings in this study.

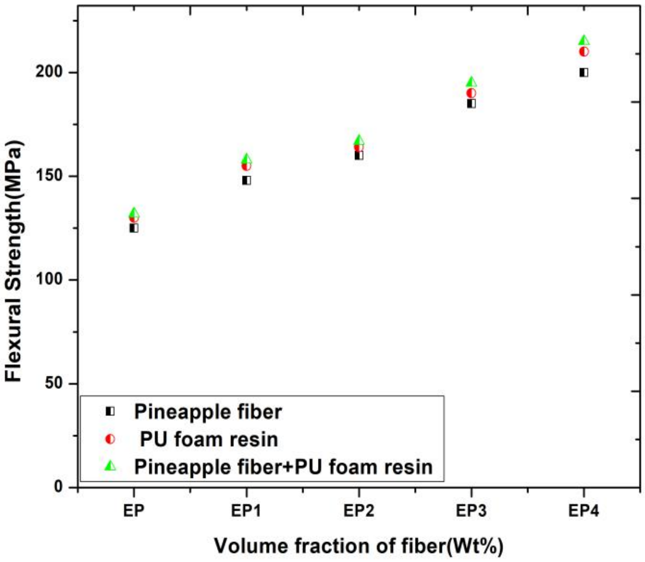

Fig.2 Flexural strength versus volume fraction of fiber

C. IMPACT STRENGTH

Figure 3 shows the amount of moisture absorbed by the test specimens. The base . 'E', a synthetic thermosetting plastic, demonstrated no moisture absorption after immersion. The inclusion of pineapple fibre resulted in a marginal moisture uptake of 0.44%. This is owing to natural fibres' ability to absorb water. PU foam reinforced composites demonstrated moderate to significant increases in moisture uptake. The initial increase of 0.81% for the 2 wt% PU foam reinforced hybrid composite led to an increasing trend in moisture uptake, with the 8 wt% PU foam reinforced hybrid composite EPN4 showing 1.16%. EPN4's high moisture uptake can be attributed to its natural ability to absorb water [14]. The addition of pineapple leaf fibre to the basic . increased its mechanical properties. PU foam significantly improved the mechanical characteristics of hybrid ./PU foam/pineapple composites. The 'EPN2' hybrid has higher tensile, flexural, and impact properties than 'E', with increases of 66.62, 57.79, and 67.95%, respectively, and 17.91, 42.72, and 44.66% for 'EP'. EPN2 has a relatively low moisture absorption rate of 0.96%. This research found that a hybrid of . Pineapple leaf fibre at 25% and PU foam reinforcement at 4% yielded the best results for frictional and shear-forced applications such as brake pads and sports goods.

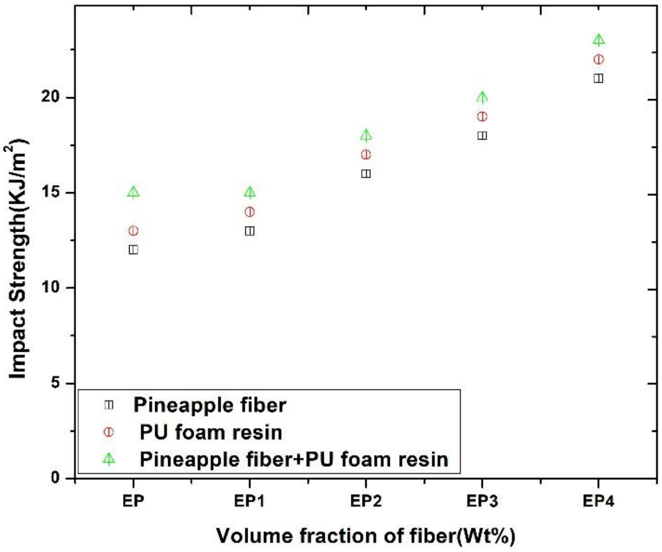

Fig.3 Impact strength versus volume fraction of fiber

D. MICRO-STRCTURE BEHAVIOUR

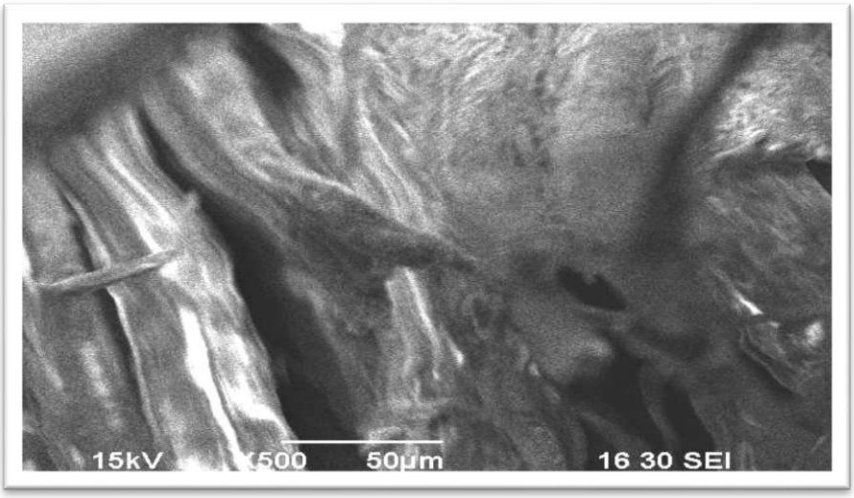

Fig.4 SEM images of natural pineapple leaf

The above Scanning electron microscopic image shows the study of the natural pineapple fibre and E-glass reinforced PU foam composite structure vinciblity in the material with give discontinues pattern. The above Scanning electron microscopic image shows the study of the natural pineapple fibre and E-glass reinforced PU foam composite structure lack of continuity, break can be seen in Fig.4.

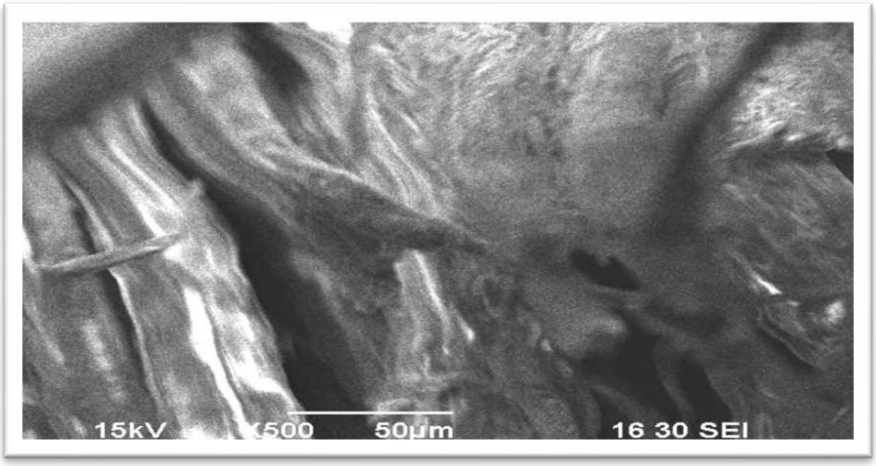

Fig.5 SEM images of Pineapple leaf + epoxy resin

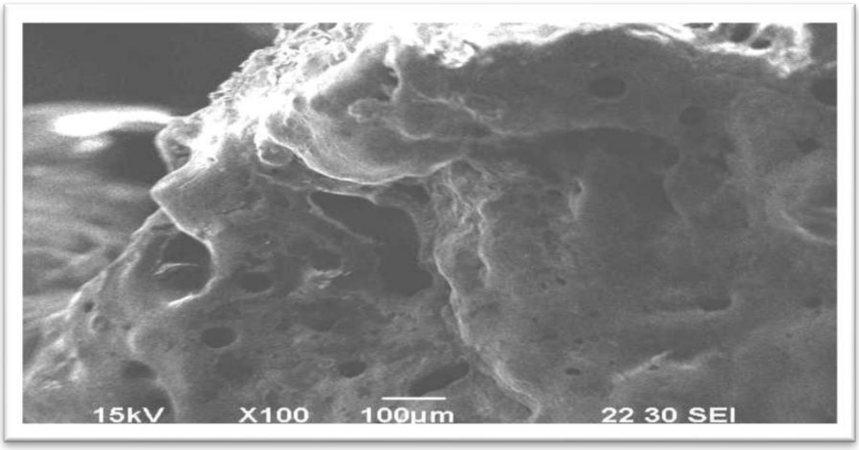

Fig.6 SEM images of Pineapple leaf +epoxy resin +PU foam

The above Scanning electron microscopic image shows the study of the natural pineapple fibre and E-glass reinforced PU foam composite structure foam hallow cavity and inadequate quality of mixture.The presence of laminates on cracked specimens indicates resistance during mechanical testing. More cracks indicate greater mechanical characteristics, while fewer cracks, as seen in the FESEM picture of plain . specimen 'E' (Figure 4,Figure 5,& Figure 6), indicate lower mechanical confrontation with the force applied during examination. The photos show agglomerated PU foam particles, which contribute to the decrease in mechanical characteristics.

V.CONCLUSION

- This study examined how distributing into an PU foam matrix and combining it with pineapple fibres resulted in a hybrid composite with superior mechanical properties.
- Four layers of pineapple fibre mats were compressed moulded with an PU foam blend to create 5mm thick composites. Curaua was added to . resin at four weight ratios (10%, 20%, 30%, and 40%), resulting in four distinct matrix materials.

- The hybrid composites improved mechanical and abrasion rates, comparable to PU Foam/Pineapple fibre composites being explored as boat frontiers alternatives.
- The presence of laminates on cracked specimens indicates resistance during mechanical testing. More cracks indicate greater mechanical characteristics, while fewer cracks, as seen in the FESEM picture of plain . specimen 'E' indicate lower mechanical confrontation with the force applied during examination.
- Higher tensile strength is achieved with compressing the layers of Pineapple leaf fiber +PU foam and lower tensile strength was reached at 30-45MPa

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