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Fabrication methodology and hardness influenced by hybrid layer of a novel Entada Rheedii and banana fibre reinforced epoxy resin composite

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ABSTRACT

In this study, the hardness properties of an innovative hybrid composite made of Entada rheedii and banana fibres mixed with epoxy resin were evaluated. A hand lay-up procedure in single or double layers was followed by fibre infusion. In comparison to synthetic and natural fibres, these combinations showed superior reinforcing and provided advantages including waste reduction. Utilising these combinations had the benefit of reducing waste disposal and treatment problems frequently encountered with synthetic composites. The project sought to improve material lifecycle management by utilising biodegradable polymers in industries like automotive, marine, and aerospace. In polymer composites, natural fibres are preferred due to their durability, low weight, cost-effectiveness, and environmental friendliness. Entada Rheedii, a new natural fibre that will improve the performance of epoxy composites, was introduced in the research. Rockwell-B hardness tests performed on the composite with double layers of Entada Rheedii and banana fibre at 45% volume fraction exhibited the highest hardness at 67 HRB. This hybrid composite holds promise for marine applications requiring essential hardness properties.

1. Introduction.

Novel biodegradable and recyclable natural fibre-reinforced polymer composites have gained popularity as eco-friendly alternatives for engineering applications, offering improved stiffness and a high strength-to-weight ratio. In contrast to synthetic fibre-reinforced composites like glass, carbon, aramid, and graphite, which boast desirable mechanical properties, their higher costs and environmental concerns have fueled the adoption of natural fibres such as sisal, flax, hemp, jute, coir, bamboo, banana, wheat husk, and sugar cane in various applications. These natural fibres provide several advantages, including easy accessibility, cost-effectiveness, and simplicity of processing, allergy-free properties, and biodegradability. The engineering sectors, especially aerospace and automotive industries, have increasingly utilized these eco-friendly materials in storage tanks, pump casings, structural components, sporting goods, and packaging. Extensive research has been conducted on the physical and mechanical characteristics of natural fibre composites, encompassing hardness, interfacial bonding, volume percentage, size, structure of the reinforcing phase, and their orientation. This study specifically focuses on evaluating the hardness analyses of composites made from Entada Rheedii fibre, banana fibre, and hybrid fibres reinforced matrix, with varying fiber volume fractions and unreinforced laminates. Hardness in materials refers to their resistance to confined deformation. The presence of combined fibres in the polymer matrix is expected to enhance the flexibility of fibre-reinforced composites.

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2. Literature Review on Hardness of Fibre Reinforced Composites.

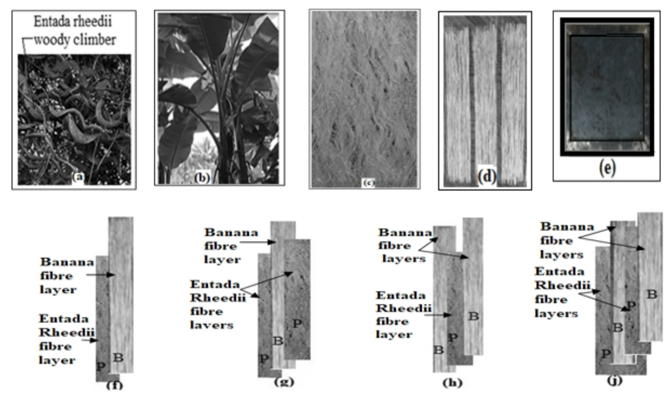
Various studies have explored the hardness properties of natural fibre-reinforced polymer composites, investigating different combinations of fibres and matrices. These composites offer potential applications as environmentally friendly and mechanically robust materials in engineering fields. Sivakumar et al. (2016) studied glass/nylon/jute fibre hybrid reinforcements in epoxy composites, with the pure glass fibre composite exhibiting a maximum hardness value of 27 HV. Madhukiran et al. (2013) evaluated pure banana and pure pineapple polymer matrix composites, which showed hardness values of 683 HRB and 708 HRB, respectively, using a diamond cone indenter. Satish Shenoy et al. (2019) conducted micro-hardness tests on Grewia Serrulata fibre reinforced unsaturated polyester composites. Acetylation and silane treatment significantly increased the hardness, ranging from 37 to 45 HV. Wilson Webo et al. (2018) investigated sisal fibre-epoxy resin composites and found that the hardness gradually increased with increasing fibre loading, reaching 51 BU at 50% weight fraction. C.V. Srinivasa et al. (2011) assessed the Rockwell-B scale hardness of areca fibre-reinforced epoxy resin matrix specimens. Increasing the volume fractions of fibres also raised the hardness, along with the composites' moduli. Yasser S. Mohamed et al. (2018) measured the micro indentation of E-glass fibre-reinforced polymer composites, observing a notable increase in hardness, measured to be 84 HV, in the reinforced polymers. Nithyashree D.G. et al. (2017) investigated the hardness properties of sisal/coir reinforced composite materials. Hardness increased with an increasing percentage of fibres, with the 40% volume fraction sisal/coir fibre hybrid reinforced polymer composite registering a hardness of 102 HRA. Chidhananda et al. (2021) examined the hardness characteristics of green polymer composites containing bagasse and coir particles in varying percentage compositions in the epoxy resin matrix. Paul Theophilus Rajakumar et al. (2022) studied the properties and hardness tests of a high impact polyethylene composite reinforced with abaca fibre. Hardness increased with abaca fibre loading, reaching a maximum of 67 shores D when abaca fibres were treated with alkaline. R. Pandiyarajan et al. (2022) created epoxy composites with silicon carbide and neem-coir fibres, resulting in a hardness of 78 shore D. Imran Musanif et al. (2018) studied coconut fiber composites with varying volume fractions, showing hardness values of 99 HRL, 100.00 HRL, and 100.80 HRL for 30%, 40%, and 50% fractions, respectively. T. Vinod Kumar et al. (2018) combined polylactic acid with water hyacinth, areca nut, and hen feather fibres, achieving a hardness of 132 HRB at 5 wt. % nano carbon. H. Ersen Balcolu et al. (2019) examined silicon carbide reinforced composites with jute and epoxy, with hardness values of 81.88 and 81.33 shore D for maximum surface and thickness. IGP Agus Suryawan et al. (2020) conducted a comparative study, revealing higher hardness in glass fibre composites due to even fibre distribution.

However, there is no reported research on the relationship between hardness and other parameters in the hybrid Entada Rheedii-banana fibre reinforced epoxy resin composite. Further investigation in this area would be beneficial to understand the mechanical properties of such composites fully.

3. Materials and Methods.

3.1. Entada Rheedii and banana fibre hybrid reinforcements.

Figure 1: (a) Entada Rheedii climber or herb,(b) Banana plant or tree, (c) Entada Rheedii fibre layer, (d) Banana fibre layer, (e) Metallic mould, (f-j) Different layers combinations of Entada Rheedii and Banana fibres .



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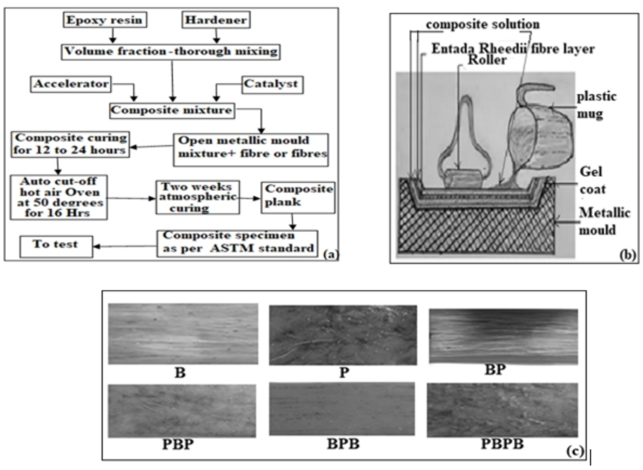
The Entada Rheedii fibre, commonly known as African dream herb, sea bean, kakkumkaya, or Parandavalli fibre (P), is a brand-new natural fibre in the world of textiles. A unique Entada Rheedii-banana fibre reinforced epoxy composite displays greater toughness in compared to existing natural fibre combinations in polymer matrix. The current study examines the hardness properties of an Entada Rheedii-banana fibre hybrid reinforced polymer, which are principally impacted by factors like the order of the fibre layers and the volume fractions of each fibre. The hardness of the resultant polymer composites increased as the volume proportion of Entada Rheedii and banana fibres increased. Entada Rheedii-banana fibre hybrid reinforced epoxy resin composites have excellent mechanical qualities, making them suitable for application in the construction of aircraft, marine and automobile body parts due to their lower cost and lighter weight without sacrificing necessary strengths. Entada Rheedii and banana fibre plants [Figure 1. (a-b)], their fibre [Figure 1.(c-d)] and fibre layers combinations are shown in Figure 1. (f - j).

3.2. Fabrication by hand lay-up method.

In the polymer industry, to create composites with varying strengths, a common practice is to add hardener to the polymer glue, typically ranging from 20% to 70%. The study prepared polymer composites using a calculated volume of epoxy resin, accelerator, catalyst, and 40% hardener, along with varying combinations of Entada Rheedii and banana fibres. Different layers of fibres, including mono layers of banana fibre (B),[Figure1(d); and Entada Rheedii fibre (P),[Figure 1(c)]; as

Figure 2: (a) Schematic of the fabrication methodology of the polymer composites, (b) Schematic of hand lay-up process of Entada Rheedii fibre layer reinforcements, (c) Specimen planks of the different layer combinations of the Entada Rheedii - Banana fibre hybrid reinforced epoxy composites.



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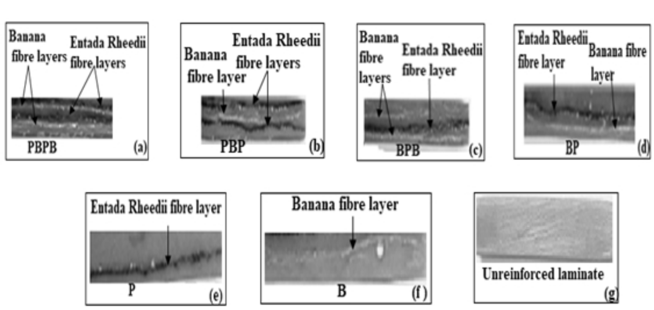
well as layer combinations such as Banana-Entada Rheedii fibre (BP), [Figure1(f)]; Entada Rheedii - Banana - Entada Rheedii fibres (PBP),[Figure1(g)]; Banana-Entada Rheedii-Banana fibres (BPB), [Figure 1(h)]; and Banana-Entada Rheedii-Banana-Entada Rheedii fibres (BPBP),[Figure 1(j)] were impregnated into the epoxy mixture in a metallic mould [Figure 1(e)]. After 12 to 24 hours of curing, the fabricated epoxy resin mixture was kept in an auto-cut-off hot air oven at 50°C for 16 hours continuously. Subsequently, the planks were left for atmospheric free air cooling for two weeks, and test specimens were cut from the planks according to ASTM D 2583 standard. The specimen planks of different layer combinations of Entada Rheedii-banana fibre hybrid reinforced epoxy composites are shown in Figure 2 (c). Various configurations of Entada Rheedii-banana fibre hybrid reinforced epoxy resin matrix layers, as well as unreinforced laminates prepared for Rockwell hardness tests, are displayed in Figure 3 (a-f) and Figure 3 (g), respectively.

Figure 3: (a-f) Different fibre - layer combinations of composite specimens, position of the fibre layers laid in the composite, and (g) unreinforced laminate.



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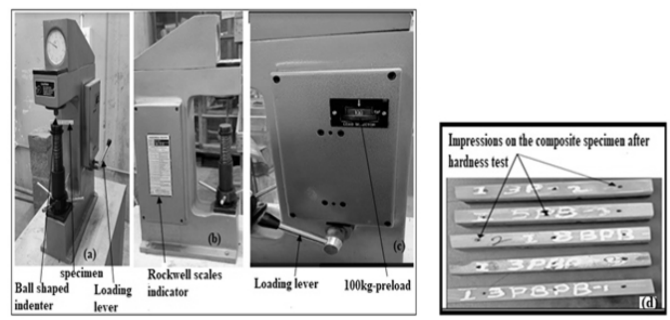
3.3. Experiment - Hardness Tests.

Hardness is the ability of a solid's surface to withstand localized deformation. By driving a strong indenter into the top of the surface, the material is forced into. The size of the resulting depression tells you how hard the material is. The composite specimens (Figure 3) were subjected to hardness tests using a Rockwell Hardness Tester [Figure 4(a- c)].

100 Kg preload was set on the Rockwell tester - B scale for polymers. (HRB /100 Kg/5 seconds ASTM D 2583 standard) Specimens size of 100 mm×10 mm×10 mm were used for the experiments of harness test.

Figure 4: (a-c). Some views of Rockwell hardness tester, (d) Composite specimens, tested for hardness, with indenter impressions.



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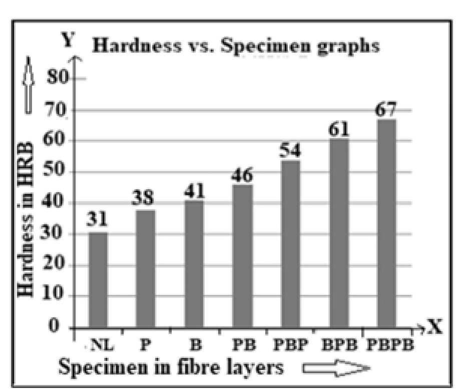
4. Results and Discussion.

Table 1 shows the variation in hardness of composites made by stacking different fibre layer combinations as well as that of unreinforced epoxy. During the construction of the composite, a 40% hardener and fibre volume fraction up to 45% were added. The hardness fluctuation in composites with loading of natural fibre layers is seen in Figure 5.

Figure 5: Hardness in HRB vs. Specimens in Fibre layer arrangement, X-axis name only as 'Fibre layers'.



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The rise in the composite's hardness is a result of the growing proportion of fibre layers within the epoxy, which leads to enhanced adhesion between the fibres and epoxy particles within the material [see Figure 6 (a-c)]. The higher volume percentage of fibres in the hybrid reinforced polymer matrix fosters stronger inter-molecular attraction between the fibres and matrix particles, ultimately contributing to the increased hardness of the composite [refer to Figure 5]. Additionally, the improved bonding between the matrix and reinforcement elements, as previously observed by S. Prakash et al. in 2016, can also be attributed to the heightened hardness of the composite.

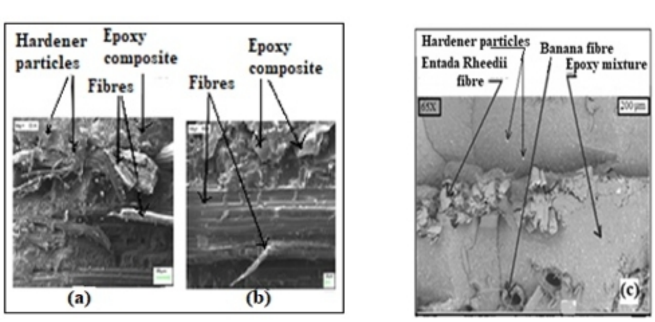
Table 1: Hardness of Entada Rheedii and banana fibre hybrid reinforced epoxy composite [NL-Nil layer or Unreinforced, P-Parandavalli or Entada Rheedii fibre layer, B-Banana fibre layer].

Specimen In Fibre layers	Banana Fibre (B) %	Entada Rheedii Fibre (P) %	Total Fibre (P & B) %	Epoxy mixture %	Hardness, HRB
N L	0	0	0	100	31
P	0	15.40	15.40	84.60	38
B	7.12	0	7.12	92.88	41
PB	7.12	15.40	22.52	77.48	46
PBP	7.12	30.80	37.92	62.08	54
BPB	14.24	15.40	29.64	70.36	61
PBPB	14.24	30.80	45.04	54.96	67

Source: Authors.

Figure 6(c) provides a clear cross-sectional view of a composite specimen, illustrating the presence of both Entada Rheedii and Banana fibres within the epoxy matrix. The increased volume percentages of fibres in the composite, along with robust intra-granular adhesion among the epoxy mixture particles [see Figure 6 (a-b)], are responsible for the composite's hardness. This behavior has also been reported by Nithyashree D.G. et al. in 2017. The highest hardness, measuring 67 HRB at 45% fibre volume fraction and 40% hardener, was achieved by the sandwich structure consisting of double layers each of Entada Rheedii and banana fiber hybrid-reinforced epoxy composite, as indicated in Table 1 and Figure 5 above.

Figure 6: (a - b) Optical micrographs of the fibre reinforced composite with hardener addition of 40% and (c) Scanning Electron micrographs of the both layers of Entada Rheedii - banana fibre hybrid reinforced epoxy resin composites with hardener.



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Conclusions.

The addition of fibre layers influenced the hardness of the epoxy composite reinforced by the Entada Rheedii-banana fibre hybrid. Such an increase in hardness resulted due to the increased dispersion of the fibre particles in the matrix leading pronounced intermolecular attractions among the hardener particles, fibre elements and the epoxy matrix. The maximum hardness of the hybrid fibre reinforced polymer epoxy registered was 67 HRB at 45% fibre volume incorporated into the matrix.

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