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Evaluating Bamboo Species for Structural Integrity: A Comparison Study

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Abstract: Bamboo's strong strength-to-weight ratio, low carbon footprint, and quick renewability make it a sustainable substitute for traditional building materials. However, bamboo's structural performance differs greatly between species, therefore a thorough assessment is required to ascertain whether it is suitable for load-bearing applications. With an emphasis on compressive strength, tensile strength, flexural behavior, modulus of elasticity, and dimensional stability, this study examines the mechanical characteristics of important bamboo species, such as Guadua angustifolia, DendrocalamusStrictus, Bambusa Balcooa, and Phyllostachys edulis. To evaluate structural integrity, standardized mechanical tests and microscopic analysis were used.

The findings show that DendrocalamusStrictus has outstanding flexural resistance and Guadua angustifolia has superior compressive and tensile strength, making it ideal for structural applications. Phyllostachys edulis exhibits favorable elasticity but poorer density, while Bambusa Balcooa, despite being commonly available, exhibits diversity in mechanical properties. The results contribute to the creation of uniform technical guidelines and emphasize the significance of species-specific selection in bamboo construction. In addition to supporting the use of bamboo in sustainable construction, this study offers vital information for future material optimization in green building techniques.

Keywords: Bamboo, structural integrity, sustainable construction, mechanical properties, comparative analysis.

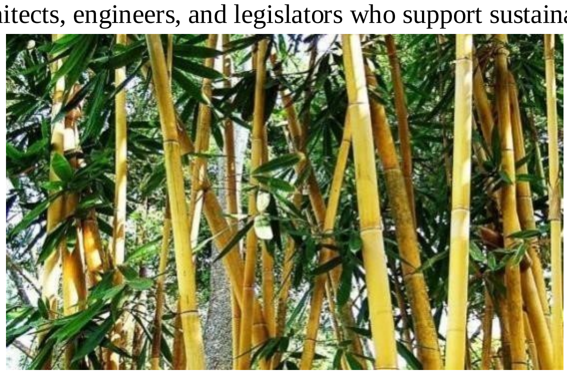
I. INTRODUCTION

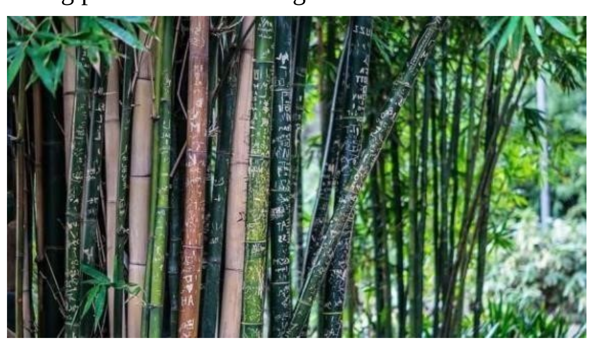
Bamboo, sometimes known as "green steel," has drawn more and more interest as a renewable and sustainable building material because of its exceptional strength-to-weight ratio, quick growth, and minimal environmental impact. Knowing the structural integrity of various bamboo species is essential for their efficient use in contemporary engineering and design, as the demand for environmentally friendly construction materials grows worldwide.

Although bamboo has long been used in many civilizations, its usage in modern load-bearing structures necessitates a thorough assessment of its longevity, performance under varied pressures, and mechanical qualities. Regarding tensile strength, compressive resistance, flexural behavior, and resistance to environmental deterioration, different species display different traits.

The purpose of this study is to evaluate the suitability of many bamboo species for structural applications, including Guadua angustifolia, DendrocalamusStrictus, Bambusa Balcooa is, and Phyllostachys edulis. The modulus of elasticity, ultimate strength, density, and dimensional stability are important factors that are being studied. By examining these characteristics, the study aims to determine which species are most suitable for building while also advancing established standards for bamboo-based engineering.

The results of this study will assist close the gap between bamboo's historic use and its contemporary structural uses by offering architects, engineers, and legislators who support sustainable building practices useful insights.





II. LITERATURE REVIEW

1) *Title: Experimental study on improving bamboo concrete bond strength Author name:* Pankaj R. Mali and Debarati Dattaa (2019)

Pullout experiments are used in this study to examine the binding behavior between bamboo and concrete. Chemical adhesives are used to render the surfaces of bamboo strips used for concrete reinforcement impervious. The water-repellent qualities of various surface coatings are assessed by testing. Steel wire wrapping, sandblasting, and various coatings are used to examine the chemical interaction at the bamboo-concrete interface. To strengthen the link, mechanical interlocking is also investigated.

The findings demonstrate that a grooved bamboo profile and surface treatment greatly increase binding strength. In terms of binding strength, the recently created grooved bamboo strip performs better than plain, treated, and untreated bamboo strips. The size and spacing of the grooves, along with the type of surface treatment, have the most effects on the bond strength. For improved bamboo-concrete bonding, these results emphasize the significance of optimal surface treatments and groove patterns.

2) *Title: Bamboo-based composites: A review on fundamentals and processes of bamboo bonding Author name: William* Nguegang Nkeuwa, Jialin Zhang, Kate E. Semple, Meiling Chen ,YelingXia ,ChunpingDai ,

This study examines the difficulties in bonding bamboo and bamboo-wood composites, emphasizing structural variations that make adhesion more difficult than with wood, such as solid cell walls and limited permeability. Optimized processing, the choice of adhesive (such as isocyanate resins over formaldehyde-based systems), and industry standards are required to increase bonding. The performance of adhesives is impacted by surface qualities that are changed by treatments like steaming and bleaching.

Although further study is needed to improve bonding procedures, hybrid bamboo-wood composites provide an affordable alternative for sustainable building materials.

3) *Title: Characterization of bamboo species at different ages and bio-oil production Author name:-* Liang ching, sushiladhikari, zhoughong Wang, yulong ding

The investigation of two bamboo species Pseudosasa amabilis and Pleioblastus chino as possible sources of chemicals and biofuels is covered in this abstract. The study examines the effects of bamboo age (one, two, and three years old) on a number of variables, including biomass characteristics, pyrolysis products, and bamboo bio-oil qualities. Here are the main ideas in greater detail: 1. The Effect of Aging on Biomass Properties Similar patterns of aging-related changes in chemical composition were seen in both bamboo species. The amount of ash (the non-organic waste left over after combustion) in the bamboo rose with age. As ash aged, its soluble portion which dissolves in water decreased while its insoluble portion which aids in the development of solid char increased.2.Goal: The study is to assess the effects of aging (i.e., the age of the bamboo during harvest, namely one, two, and three years old) on the features of the resulting bamboo bio-oil, the distribution of pyrolysis products, and the qualities of bamboo biomass. 3. The Impact of Aging on Bamboo Biomass: As the bamboo biomass ages, its chemical makeup shifts. As the bamboo ages, the biomass's ash content rises. While the insoluble portion of the ash helps produce char during pyrolysis, the soluble portion of the ash diminishes with age.4.Chemical Composition and Aging: As they aged, both bamboo species showed comparable patterns in changes in chemical composition. Interestingly, as the bamboo grew older, its ash content rose while its soluble ash percentage fell. During pyrolysis, the insoluble ash component was crucial to the creation of char. Furthermore, there were more syringyl units in the lignin of these bamboos than guaiacyl ones. Both species had greater heating values (HHV) in the 19.4–19.9 MJ/kg range. Product Distribution of Pyrolysis: The two species' distribution of pyrolysis products was identical. The amount of water-free bio-oil produced by the bamboo increased with age. This implies that elder bamboo might produce bio-oil more effectively.

4) *Title: Engineered bamboo and bamboo-reinforced concrete elements as sustainable building materials Author name:* - Anu Bala, Supratic Gupta

The study emphasizes the promise of engineered bamboo materials as valuable, sustainable substitutes for structural applications, especially laminated bamboo and bamboo scrimber. When it comes to mechanical qualities, bamboo scrimber outperforms laminated bamboo.

The study also investigates the use of bamboo as reinforcement in concrete, discovering that 4% bamboo reinforcement maximizes strength and fracture control. Performance is greatly impacted by treatments and coatings, particularly when bamboo is subjected to pyrolysis at high temperatures. Compared to laminated bamboo, bamboo scrimber chars more slowly, and fire-retardant coatings assist reduce heat and harmful emissions.

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Furthermore, mechanical anchorage and water-repellent coatings strengthen the link between bamboo and concrete. Bamboo-reinforced concrete (BRC) is a promising material for low-cost housing since it can tolerate temperatures above 500°C and works well with lightweight, reasonably priced wall systems.

5) *Title: Bond performance between surface-modified bamboo bars and concrete under pull-out loading Author name:* - Gaofei Wang, Yang Wei, Si Chen, Kang Zhao, Zhengyan Zhou

The bonding performance of bamboo bars in concrete is examined in this study, highlighting bamboo's potential as an affordable and environmentally friendly substitute for conventional materials like steel. Forty bamboo-reinforced concrete specimens were subjected to pull-out tests, taking into account varying surface modifications (unmodified, epoxy mortar (EM), and polyurethane (PE)), equivalent diameters, and development lengths. Important conclusions include: Whereas EM-modified bars failed because of bamboo bar stress, PE- modified bars failed mostly because of pull-out. Four separate stages were visible in the bond stress–slip curve: micro-slip, slide, declining, and residual. The maximum average peak bond stress was attained with EM-modified bars. As growth length and diameter increased, bond stress reduced. Near the loading end, the strain was at its highest.

To improve knowledge and use of bamboo as reinforcement in concrete buildings, the study also created bond stress–slip models for PE-modified bars.

6) *Title: Pull-out strength of the glued-in joint in laminated bamboo structure Author name:* - Yan Feng, Ming Xu, Yao Xu, Liuhui Tu, Sunyue Chen

Since its initial proposal, the glued-in joint has demonstrated its dependability, usefulness, and flexibility in concrete and timber structures. Twenty-seven specimens in a pull-pull configuration were used to investigate the pull-out strength of the glued-in junction in laminated bamboo structures. Through monotonic pull-out tests parallel to the grain, the effects of several parameters, including the rebar's edge distance, glue thickness, rebar diameter, and anchorage length, were evaluated. The experimental results described three failure modes: pull-out, failure of rebar after yielding, and breaking of laminated bamboo block. Based on the trial results, it was determined that limiting the rebar's edge distance within a suitable range might prevent the first failure scenario.It was discovered that the rebar diameter and anchorage length might be used to determine the initial stiffness and load- carrying capability of the latter two failure scenarios. The viability of the conventional approach was examined in light of the existing theory, and a simplified formula was created using the experimental findings and theoretical deduction, which demonstrated that the diverg+ence was less than 6%. Lastly, suggestions for the laminated bamboo structure's glued-in joint design were given.

III. PHYSICAL PROPERTIES OF BAMBOO

Bamboo's high specific gravity (SG) and its variance throughout the culm wall can impact heat and moisture transmission, adhesive penetration, and composites pressing when compared to softwoods [7, 8]. According to a study by Febrianto et al. [9], using highdensity bamboo to create strands results in a minor increase in internal bond (IB) strength because the substrate needs more force to rupture if the bond effectively transmits loading stress to the nearby bamboo [[10], [11], [12], [13]]. Using wood with varying SG, Dai et al. [8] and Frihart et al. [14] observed comparable outcomes. Due to their varying densities, bamboo and wood components used in hot-pressed composites have various compression ratios, which in turn impacts bond strength. Maulana et al. [15] used two bamboo species with varying densities to create oriented strand boards (OSB). Since improved bonding and higher panel density result from greater contact area [16] and pressure [17] at the interfaces between strands, they discovered a positive linear link between IB and compression ratio. However, because of the increased release of compressive stress, an excessive compression ratio causes the thickness to inflate with water absorption [18]. According to Semple et al. [19], bamboo strands did not compress as much as aspen wood strands during normal wood OSB pressing. This alters the compaction ratio and strand surface contact pressures, increasing the strength of the internal bond and decreasing the behavior of moisture-induced swelling.

IV. SURFACE CHARACTERISTICS AND CHEMICAL COMPOSITION OF BAMBOO ELEMENTS

The resin flow, penetration, bond formation, and performance of the resultant composites are all influenced by the geometry of the components and process-induced features including surface roughness, fractures, and heat treatment of bamboo elements [20,21]. Round bamboo culms can be flattened with few surface cracks when steam softening (at 140 °C) is used. Nevertheless, cracks may form at lower softening temperatures (100–120 °C) [21], causing resin to move away from the bond line and result in resin hunger or overuse of resin (Fig. a1).

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The surface of more recent flattened bamboo (Fig. a2) is roughened or "fiberized" for better bonding without forming deep, wide fissures that use more resin. It requires a large number of tiny fissures and cracks to fracture the smooth, impermeable culm cortex. Excessive cracks are visible across the culm wall of some first-generation bamboo scrimber (Fig.b1-3), which lowers production and resin use efficiency. Bamboo bundles treated with heat or carbonization to increase their dimensional stability and resistance to biodegradation also exhibit color changes in Figs. b2 and 3. As will be covered later, these treatments may also impair the performance of resin spreading, penetration, and bonding. Damage to the surface (Fig. c2) can lead to decreased mechanical qualities and bonding strength, while geometric changes in bamboo strands (Fig. c1) can impact heat and moisture transmission that affects resin curing. Bamboo strands' surface roughness can vary due to machining issues; for example, woodsuited knife designs and machine settings might dislodge parenchyma tissue, resulting in a fragmented surface. Slicing bamboo requires some adjustment to preserve element quality [22].

V. CONCLUSION

With an emphasis on important mechanical characteristics such compressive strength, tensile strength, flexural strength, and durability, this study assessed the structural integrity of several bamboo species. The results show notable species differences, with Guadua angustifolia and Dendrocalamusstictus standing out as the best due to their favorable fiber density and high strength-to-weight ratios. However, despite being widely accessible, species such as Bambusa balcooa showed reduced structural reliability when subjected to high stresses.

The necessity of uniform cultivation and treatment procedures is highlighted by the discovery that environmental factors, including harvesting age and growing circumstances, also affect mechanical performance. Furthermore, endurance was increased by treatment techniques (such as heat or chemical preservation), though occasionally at the expense of decreased flexibility.

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