

Fundamental Concepts of Bamboo: Classifications, Properties and Applications



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Abstract With the development up to 75 cm in a solitary day, Bamboo has enrolled its name as quickest developing plants on the planet. It's being utilized in various areas in various works and furthermore being utilized for building materials and so forth at a bigger scope. In the event that we will contrast Bamboo and steel, at that point can see that Bamboo is a lot less expensive than steel even Bamboo properties like high elastic, adaptability, light weight, sturdiness is obviously superior to the next structure materials. Right around 500 unique types of bamboo has found in our universe even in some cases inside several subspecies can check their quality. One of the heavenly bamboo "Guadua angustifolia" found in Colombia which gives a higher caliber of timber straight and solid. Two subspecies of bamboo known as 'guadua

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castilla' and 'guadua mecana' exist in nature which height comes to up to 25 m and a breadth up to 18 cm. Presently in current situation there are a significant number of businesses are looking forward as an elective choice in type of Bamboo due to having properties like reasonable, bottomless, minimal effort and great explicit quality. In this current research scarcely any audits and explores on the warm, mechanical and some different properties like high malleable, light weight, durability and so forth have been appeared. The audits incorporate how the specialists set up their investigations, the bamboo species utilized and the outcomes got.

Keywords Frames of bamboo · Green buildings · Power bamboo · Qualification tests · Bamboo power · Bamboo · Mechanical properties · Physical properties · Green building · Sustainable development · Compression test

1 Introduction

Among the grass family 'Poaceae' and the subfamily 'Bambusoideae', Bamboos are pine eternal blooming trees. The term 'bamboo' derives from the Dutch or Portuguese languages that likely appropriated it from Malay. Bamboo material is a standard fabric built up from the pulp of the bamboo grass, the bamboo filament is subsequently built up through mashing the bamboo grass till it discrete into thin themes of filament, which is afterward revolved and washed for working into cloth. Bamboo filament is alike to the mushiness of silk. Because of its flexible effects, bamboo filaments are utilized mostly in fabric industries for making bath robes, attires and towels. Because of its hygienic creation, this is utilized for preparing sanitary napkins, bandages, nurse wears and masks. In contrast with the past, many significant industries related to aeronautics, furnishing and construction, sought for composite materials due to their overwhelming advantages such as lightweight and its durability. For example, aircraft manufacturers have increased the usage of composite materials in manufacturing aircraft. However, environmental concern is one of the downside of using composite materials. In view of most conventional composites are non-renewable and non-recyclable, pollution complication has become an issue when conventional composites are used. Natural fiber compounds have taken the contemplation of numerous industries as another substances, as their current emphasis on environmental- friendliness and sustainability.

A grass which can enlarge until 25 m within six months is known as Bamboo [1]. Every Culm appears from the earth surface at its last diameter (i.e. its girth does not enlarge throughout its existence), narrowing as it enhances in height, and extending in y-direction by cell-division "telescopically" in the middle of the intersections (i.e., the space in the middle of intersections enhances as this extends). One time completely extended, culms constantly take three to five years to grown-up to brimful power, through which they occurrence lignifications and silification. Subsequently an interval of five to six years, the culms' power starts to worsen. Internationally there are about hundred reputed "woody" herbs favorable for establishment. Clumps (Combine

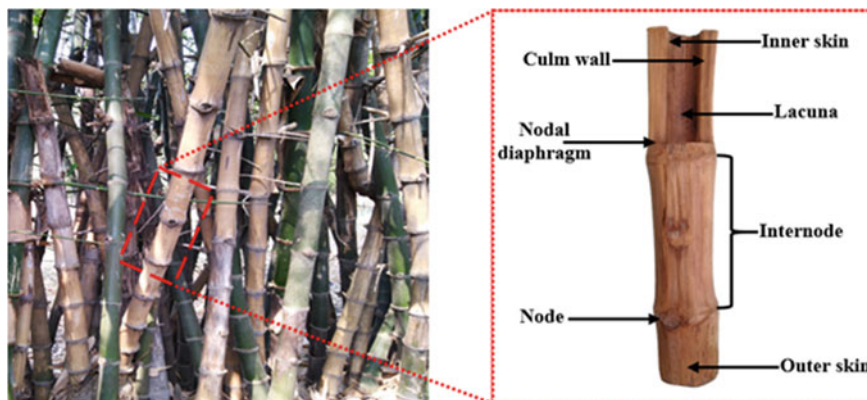


Fig. 1 General structure of a bamboo culm

of culms enlarging at a time) of the big woody herbs usually outstretch highest creation afterward around seven years and can continue systematic supplying of about 20–25% during their high-yielding lifecycle. The stem, or Culm, is fragmented through intersections, the straps at systematic gaps. The intersection evident as a shield to the inside of the Culm, that assists to avert augmenting of the partitions. The area in the middle of intersections is termed as the internodes, as represented in Fig. 1; the intermodal placing differs across the Culm and in the middle of strains. Inside the internodes, vascular bundles and cellulose fibers rush aligned to the span of the Culm [2, 3], while at the intersections they engrossment, accompanied by few of them interchanging into the nodal shield [1].

2 Historical Background of Bamboo

In its standard form, bamboo as a fabrication substance is conventionally connected accompanied by the arts of the South Pacific, South Asia, Central, South America and East Asia. In India and China, bamboo was utilized to setback effortless interruption bridges, either by preparing cables of twisting or split bamboo entire culms of adequately flexible bamboo jointly. Such kind of bridge near to Qian-Xian is mentioned in communicating dating back to 960 AD and may have nestle from far back as the third century BC, due mainly to steady preservation. Bamboo has also long been utilized as framing; the exercise has been prohibited in China for buildings above the six stories, however is motionless in steady utilization for super-structures in Hong Kong [4]. In Philippines, the nipa shed is an impartially classic e.g. of the maximum fundamental kind of housing where bamboo is utilized; the partitions are fracture and woven bamboo, and bamboo begins and poles may be utilized as its support. In Japanese architecture, bamboo is utilized essentially as a supplement oridentifying element in buildings such as fencing, fountains grates, and

gutters, mostly because of the ready generous of standard timber [5]. Some regions in India, bamboo is being utilized for drying cloths indoors, both as rod elevated up close to the ceiling to put cloths on, and as a stick welded accompanied by acquired expert skill to hoist, spread, and to take down the cloths when dry. It is furthermore frequently utilized to construct steps i.e., aside from their standard performance, are too utilized for supporting bodies in burials in Maharashtra, the bamboo copses and jungles are known as veluvana, the title velu for bamboo is more appropriately from Sanskrit, while vana defines jungle. Moreover, bamboo is further utilized to generate bars for saffron-colored, Indian flags, which can be noticed that flying throughout India. Bamboo has created an important fragment of the raising heritage in Central and South America [1]. Vernacular creates of building such as bahareque have established that utilize bamboo in extremely churning regions. When arranged and in superior circumstances, these have been seen to execute curiously best during earthquakes [6].

3 Origin of Bamboo

Bamboos expand in the subtropical and tropical areas of Latin America, Asia and Africa, enlarging as faraway north as the southern United States or Central China and as far away south as Patagonia. They too enlarge in the regions of Northern America. The record of Chinese people transplanting and utilizing bamboo can be followed backward, 7000 years. As quick as Shang Dynasty (sixteenth-eleventh century B.C.), bamboo was earlier utilized in different feature of earliest Chinese people's day today lives. It was utilized for clothing, food, housing, musical instruments, transportation and also weapons. In the opinion of Patrick Malcolm, gold colored bamboo was the 1st of the Phyllostachys bamboo varieties to be instigated within the country United States, in 1882. In Alabama, where Bamboo was to be first utilized as rapid enlarging for barrier of wind, it was transplanted through southern tobacco countryman. A record of few repeatedly utilized systematic pieces across the globe shown in Table 1.

3.1 *Suitable Structural Species*

The subsequent attributes of bamboo pieces that have conventionally been utilized for fabrication are as follows:

- Enlarge regionally in prosperity
- Powerful than other regional pieces
- Huge size (50–200 mm in diameter)
- Enlarge comparatively linear or vertical
- Grown-up rapidly (3–5 years)

Table 1 Represents a record of few repeatedly utilized systematic pieces across the globe [7–9]

Scientific name (local name)	Areas found	Diameter (mm)	Solid/hollow
Guadua angustifolia Knuth	South America	120–160	Hollow
Dendrocalamusstrictus (Calcutta)	Asia	25–80	Hollow
Bambusa vulgaris	Africa, Asia, South America	80–150	Hollow
Phyllostachys edulis (Moso)	Asia	120–180	Hollow
Dendrocalamusasper (Petung)	Asia, South America	80–200	Hollow
Bambusablumeana (Spiny/Thorny Bamboo)	Asia, Asia–Pacific	60–150	Hollow
Gigantochloapus	Asia	40–100	Hollow

- Somewhat additional impenetrable to insects and fungi (Beneath liveliness content)
- Smaller permissible to breaking.

3.2 Behavior in Earthquakes

There is a usual misinterpretation that the substance bamboo is anyhow ‘miraculously’ superior in earth tremors. As a matter of fact a discrete characteristic this holds various brittle failure manners that could influence its churning execution. Constructions of bamboo have historically executed well in earth tremors firstly due to their insubstantial creation (elevated power-to-heaviness proportion), and subordinately due to their potential to suck up vitality at relations, mainly when utilizing pins. It has been noticed afterwards earth tremors in jargon constructions such as Bahareque [10], which usually utilizes pinned relations. The workable creation of few conventional bamboo buildings may too be approvable in earth tremors, however it is not an attribute which can be effortlessly utilized in current buildings that tend to be weightier, have lesser motion liberalities and need a substantial assurance of power to earth tremors than conventional constructions. Present bamboo formations normally need elevated power gobbled relations accompanied by plaster that are regrettably comparatively hard. But, while satisfactory operation tremorous blueprint ideas are registered in coexistence accompanied by additional regionally ductile relations like pins, greater earth tremor resistance and altogether construction ductility can be attained [11].

3.3 Fire Considerations

Bamboo acts as a same path to wood in flak, which burns at a moderate and probable rate and is additionally a bad conductor of hotness; hence the bamboo in back of the blackened coating persists practically safe. However, restricted flak experiments have been performed [12], this is feasible to presume burning rates same as those for wood (e.g. 0.6 mm/min), and due to the culm partitions are so narrow this is practicable to judge that afterward blazing for just a some minutes the narrow partitions will begin to misplace power quickly. It proves that an optically displayed bamboo construction would hardly be favorable for positions where there is no flak resistivity demand like roofs and probably the partitions of single-storey constructions. It has rarely been utilized for two-storey dwellings [13], however hardly in positions where flak rules are not meticulously related or where the bamboo is sufficiently defended through e.g. cement furnish.

3.4 Specification of Bamboo

When identifying bamboo, this is supreme to confirm that it appears from a supportable origin and is gathered, obtained and optically categorized through an esteemed and experienced company. Standard norm should be incorporated in an identification shows in Fig. 2.

4 Classification of Bamboo

Bamboos have a special inspection and their excellent fruitful actions are honestly engrossing to examine. Bamboo is a segment of the accurate grassland ancestry, and builds up the huge and most fruitful organ of grassland ancestry. Over 1000 pieces and 91 genera of bamboo exist all-round the globe and they enlarge in a broad area of weather and topographical circumstances. Bamboo has the capability to enlarge in the regions, which extends from the Sub-sarahana shun of Africa, to the snowy mountain territory of the Himalayas. This has a lengthy and brief record and is one of the greatest flexible plants in the globe. The majority of the pieces are local to the equilaterals of Asia, even though some variation is local to the United States, *Arundhenaria gignatia*. The dimensions of bamboo pieces differ rapidly. The little variations enlarge to an elevation of 11 in., when massive wood bamboo can outstretch elevations of over 100 ft. But, few of them have been represented under the succeeding categorization sector shows in Fig. 3.

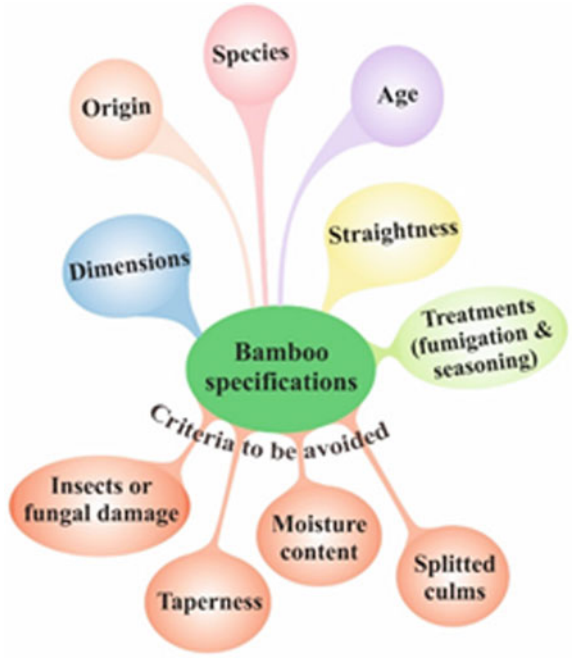


Fig. 2 Specification of bamboo



Fig. 3 Classification of bamboo [14–19]

4.1 *Fargesia*

Fargesia is a subfamily of blooming herbs in the grassland ancestry [20]. These bamboos are origin firstly to China, accompanied by some pieces in Vietnam and in eastern Himalayas [21]. Few pieces are cultured as decorative, accompanied by general title introducing sunshade bamboo and jet bamboo [22]. These are average to few elevation clustering bamboos, origin to alpine conifer jungles of East Asia, from China south to Vietnam and west to the eastern slopes of Himalayas. These are called in Cines as Jian Zhu, defining ‘arrow bamboo’. The technological title was stated in privilege of the French promoter and layman botanist Paul Guillaume Farges (1844–1912). *Fargesia* are few of the globe’s robust bamboos, however, they do not escalate strongly. General bamboos in the subfamily *Fargesia* are important nutriments for enomorous pandas, and the current blooming *Fargesia nitida* has had a destructing outcome on panda community. Due to *Fargesia* are fetching finer called for their dumpy clustering practices, they have suit economical and obtainable at most of the nurseries.

4.2 *Bambuseae*

The *Bambuseae* are the maximum various ethnic groups of bamboos in the grassland ancestry. They comprises of wooden pieces from tropical areas, incorporating few giant bamboos. Their sister category are the less herbaceous bamboos from the tropics in tribe *Olyreae*, while the temperate of woody bamboos are additionally hardly connected. The *Bambuseae* are the various tribes of bamboos in the grassland ancestry (*Poaceae*). They includes of woody pieces from tropical area, introducing few giant bamboos. Their sister category are the less herbaceous bamboos from the tropics in tribe *Olyreae*, while the temperate of woody bamboos are additionally hardly connected. The *Bambuseae* drop into two clades, analogous pieces from the Paleotropics (subtribes *Bambusinae*, *Hickeliinae*, *Melocanninae*, and *Racemobambosinae* and from the Neotropics [23, 24].

4.3 *Guadua*

Guadua is a Neotropical group of spiny, collecting bamboo in the grassland ancestry, scaling from modest to extremely huge pieces [25–27]. Substantially, *Guadua angustifolia* is famed for existence the greatest Neotropical bamboo. The group is same to *Bambuseae* and is occasionally covered in that group. Various animals are, to a different range, linked accompanied by stance of *Guadua* bamboo, for example various pieces of seedeaters, and the Amazon and Atlantic Bamboo Rats [28]. According to practical approach, *Guadua* is the most vital American bamboo.

Because of its standard, the group has been plenty utilized for home buildings across the inter-Andean watercourses of Colombia and in coastal Ecuador. *Guadua angustifolia* indigenous to Tropical America, is steadily flattering well known one time afresh as a constructing substance. Really acknowledged by Simon Bolivar for its watershed shielding and worshiped by Alexander von Humboldt for its extensive diversity of utilizations, it is being utilized in building today in South America. Scientific investigations of bamboo's mechanical attributes ("vegetable steel") have enhanced interest in its utilization. Even though bamboo culms utilized for construction can be gathered in original jungles, excess misuse guides to the exhaustion of original assets. *Guadua angustifolia* can be utilized in huge volume, when the administration of sustainable bamboo jungles and copses, also the development of new nurseries and farmsteads, is a primary task. Tropical bamboo can be cultivated accompanied by trimmings or by casing entire culms accompanied by ground. New herbs will germinate in the coming year. Or, *Guadua* can be cultivated further quickly through the chusquin technique. Culms are trim at soil level when collecting gives rise to numerous little shoots in this technique and latest herbs to enlarge across the primal herb. This technique is acceptable for huge amount jungles or farmstead collaborative. Hence bamboo is a grassland, collecting it down to the ground convinces extra latest shoots to appear, exactly similar to turf grassland. It is circumstances not called in tropical hardwood jungles. Recently quick techniques have been established by the utilization of tissue culture. Bamboo cultivated in a laboratory in the area of 1 m² will be enough to develop one hectare of new jungle. This herb can too be gladly conveyed in a one-half-cubic-meter box. Collecting can start 6 years succeeding transplanting, preparing bamboo a prospective origin of tropical renewable creation for industry (e.g., bio fuels). For architectural grounds, *Guadua* is the selected bamboo pieces. This diameter is steady for the first 15 m and after that tapers at the top. This quality has dazzled the awareness of architects, artists, designers, civil engineers, and academics. *Guadua* is additional constructive at separating CO₂ from the surroundings than all other tropical jungle environmentally; recent investigations in Colombia have now been correlated through the Environmental Bamboo Foundation. From the above investigations, Japan and the Netherlands have both accepted enormous plantation projects as a path of obtaining so-called "carbon credits" to balance the rate of contamination in industries.

4.4 *Pseudosasa Japonica*

The reed bamboo of *Pseudosasa japonica* [29] or metake [30] is a piece of blooming herb in the grassland ancestry Poaceae, origin to Japan and Korea. This robust bamboo generates copses up to 6 m (20 ft) height accompanied by shiny leaves up to 25 cm (9.8 in.) long [30]. The culms are commonly yellow-brown and it has palm-like leaves. The usual title, "arrow bamboo" outcomes from the Japanese Samurai, utilizing its solid and rigid canes, for their shafts [29]. This cool robust bamboo pieces (tolerant to 0 °F/−17.7 °C) enlarges completely both in shadow and

brimming sunlight. *Pseudosasa japonica* does completely in vessels and salty air close to the ocean. Due it tends to be huge shadow tolerant than other bamboo pieces it is repeatedly utilized through planters as a copse to a tree-lined living barrier [31]. In planting in the UK this herb has obtained the Royal Horticultural Society 's Award of Garden Merit [30, 31].

4.5 *Chusquea Culeou*

Chusquea Culeou, the Chilean bamboo [32] (Spanish: *Cana Coligue* or *Colihue*) is a breed of blooming herb in the grassland ancestry Poaceae. The bamboo, origin to South America is always evergreen, dissimilar huge breeds inside the group of *Chusquea*, this is frost-tolerant and hence plenty propagated in temperate areas. This is origin to the Valdivian rainforests, humid temperate jungles of Chile and south-western Argentina. *Chusquea Culeou* is a cornerstone breeds that can manage designs of jungle energetic through upcoming reanimation of tree breeds [33–36]. Extending to 8 m (26 ft) height through 1.5 m (4.9 ft) wide, *Chusquea Culeou* generates a considerable cluster of plants. This has shaggy lanceolate leaves accompanied by a spine on their ending, and its bloom is a whisk of gleam brown colour. The herb too generates a caryopsis fruit. Blooming occurs after the variable times that could valid for 60 years. Afterwards flowering and delivering its nuts, then the herb plant expiry. The cane is straightforward up to 6 m (20 ft) in tall, and was utilized through the pole of their spears. They are still utilizing through the Mapuche people for a musical instrument known as *trutruca*. An attribute of this *Chusquea* is that the stalks are rigid, dissimilar from most of the bamboos. *Chusquea Culeou* is propagated as an attractive herb in gardens. This herb has obtained the Royal Horticultural Society's Award of Garden Merit [32, 33, 37].

4.6 *Sasa*

Sasa, also called broad-leaf bamboo, is a genus of running bamboo. These species have at most one branch per node. *Sasa* is a group of brownie rushing bamboos maximum of which have vast, small leaves. Maximum are from Japan and are convenient in the lawn for earth shield, contrasting appearances, and as vessel herbs. They conveniently obtain no larger than 6', have one fork at each intersection and glance finest enlargement in little shadow. Cutting down is in the springtime. Sole of the *Sasa* herb types, *Sasa Palmata* is a pine bamboo expanding to 2.5 m (8 ft) by 5 m (16 ft) at a rapid rate. It is robust to area (UK) 7. This is in leaf all year. The type is hermaphrodite (has a both male and female organ) and is fertilized through Wind. This is noticed for stunning fauna. Favorable for: light (sandy), medium (loamy) and heavy (clay) soils. Acceptable PH: acid, neutral and basic (alkaline) soils. It can grow in semi-shade (light woodland). It prefers moist soil.

5 Classification and Taxonomy of Bamboo on Construction Basis

Bamboo as a constructing substance has elevated contraction power and small mass has been sole of the maximum utilized constructing substances as assist for concrete, specifically in those positions where it is launched in prosperity. Bamboo as a constructing substance is utilized for the building of scaffolding, and structures, houses. Worthful bamboo herbs for buildings incorporate the types of the group: Guadua, Dendrocalamus and Phyllostachys, of which the family of Guadua angustifolia is origin to South America and has the greatest attributes for building jointly. Classifying bamboo has consistently been somewhat a laborious job [38], mostly for non-scientists that occur to be most of the people who required acquiring these details. It is due to the multiplex botanical titles. This proposes to clarify the creatures or people of those who would approach to utilize bamboo more regularly [39], generated a record of ‘popular’ bamboos, accompanied by both their botanical and familiar titles. Ten of the most familiar bamboo species are represented in Fig. 4.

Although out of all the Botanists, there have been substantial discussions on bamboo categorization and recognition over time [38]. The discussions occasionally give the outcome as change of titles or even re-categorization. Hence, it is very tough to have a universal categorization. But, the botanical titles of their geographical position, genera, and the species are utilized as clarified statistics. Additional data like botanical drawings Photos, vernacular names, descriptions etc., can also be friendly.

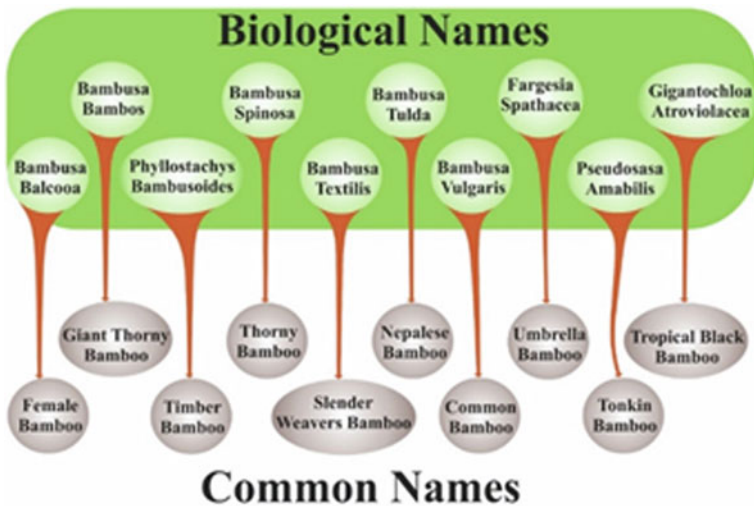


Fig. 4 Popular bamboo with biological and common name

5.1 Descriptions of Bamboo Anatomy and Structure

The analysis of bamboo reports its shape which regulates its eventual mechanical properties. Figures 5 and 6 represents the bamboo culm contains of 3-important parts:

- The stalk—fragment enlarging over the soil that may be linear orbend.
- The stalk foundation—bottom fragment of the stalk which expands into the ground.
- The stalk pedicel—the bottom fragment of the stalk, built up of additional blast segments.

The culm is constructional built of the intersections or midsections, and the segments [40]. The intersections comprise of cells cover aligned or parallel to the intersections, while the segments have lengthwise placed cells. Culms are normally hollow, namely tubes that provides the wall thickness as the dimension in the middle of the internal and the external surface of the stalk, but, few herbs accompanied by ground culms [41].

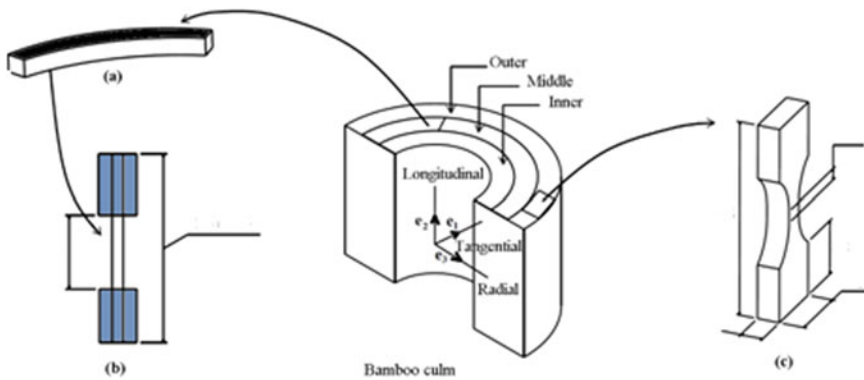


Fig. 5 Basic parts of bamboo culm



Fig. 6 Hollow and solid culm bamboo

6 Properties of Bamboo

Bamboo is repeatedly explained as extremely long lasting, but, it is mainly in accordance to the continual development of the bamboo herb and not remarkable about the long-lasting of the bamboo stalks. Real utilization, treatment, perpetuation and supervision can secure magnificent long lasting as the bamboo constructions are of more than two hundred years older, however, this is vital that the finale user is really notified to build the maximum of their bamboo outcomes. Researchers have investigated and described on the use, refining and the characteristics of these growing substance as a replacement to the enhancing reduction of wood in the jungle. The characteristics of bamboo and its coated outcomes or products verify to its power in replacement of wood. Use of bamboo has enhanced notably in the wood and wood outcome or product industries, accompanied by sufficient exchanging in most of the processing firms in the locality. In order with the establishment and utilization of bamboo-laminated wood for the reason of wood in furniture manufacture, the formation of bamboo farmsteads on degenerated lands will importantly bear manufacture and reduce the humiliation of jungle.

7 Mechanical Properties of Bamboo

The mechanical properties of bamboo rely on many components like species, culm position, and age and so on. These factors affect the fiber density of the bamboo at specific location on the bamboo. The density of the fiber will determine the strength of the bamboo. Next to these components, it is too noticed that bamboo is an orthotropic substance in natural, signification that it has dissimilar mechanical properties in the length wise, incidental and radial direction of the bamboo [42]. They showed that as the distance of the bamboo culm from the ground increases, the ultimate compressive strength also gradually increase due to the increase in fibre density. This also means that the ultimate compressive strength enhances from the internal part of the bamboo to the external fragment. According to the research collection by Janssen, dry bamboo has a better mechanical property when compared to wet bamboo [43]. Besides that, bamboo with thicker wall has better mechanical properties generally. According to Janssen, various herbs of bamboo has various mechanical properties and bamboo has the best mechanical properties when they are aged between 3 and 7 years old [43]. Young and old bamboos have lower mechanical properties [43]. According to Amada and Untao, the optimum age occurs around 2.5–4 years old [44]. Numerous tests and studies had been done by researchers on the mechanical properties of bamboo, especially on their tensile and compression properties. For example, the tensile properties of various bamboo herbs have been studied through several authors such as moso bamboo [45], and so on. However, the results obtained might differ from one study to another as different approaches are used. The species of the bamboo, specimen size and shape, presence of node and the condition of the bamboo used are different.

7.1 *Tensile Properties of Bamboo*

Lakkad and Pattel conducted an experiment to regulate the mechanical properties of bamboo [46]. This species of the bamboo utilized is unknown but it is mentioned that dry bamboo was used. The dimension used is 6 mm (T) \times 12 mm (W) \times 200 mm (L). No nodes are present in the specimens. From the experiment, the ultimate tensile strength and ultimate compressive strength of bamboo is 193 MPa and 68.4 MPa, respectively. In term of particular power, the certain tensile strength of bamboo is 214.4 km²/s², which is 4 times greater to the specific tensile strength of mild steel which is 50.6 km²/s². From this experiment, it has also found that the specific modulus of elasticity of bamboo is comparable to unidirectional glass reinforced plastic (GRP) but lower than the specific modulus of elastic of mild steel [47]. The particular characteristics give a perception into relative strength and stiffness on a mass basis, especially under single direction loads [47]. Li [45] has conducted tensile test and compression test on moso bamboo. The tensile and compression specimens have nodes in them. Hojo et al. [43], have conducted studies on the tensile characteristics of bamboo mat-reinforced compound. The reasons behind choosing bamboo fibre mats over natural bamboo fibbers are simpler manufacturing process, lower cost and the short length of original natural fibers. The bamboo fibre mat used has a bamboo fibber's density of 1.293 g/cm³ and unit area weight of 907 g/m².

7.2 *Compressive Properties of Bamboo*

Compressive properties of bamboo of different species have also been studied by researchers. For e.g., the contracting properties of various bamboo herbs which have been earlier moved out through authors are Kao Jue (*Bambusa pervariabilis*) [48], Mao Jue (*Phyllostachys pubescens*) [48–50], *Bambusa balcooa*, *Bambusa bambos*, *Bambusa nutans*, *Bambusa tulda*, *Dendrocalamus giganteus*, *Dendrocalamus strictus*, *Melocanna bambusoides* [51] and Hawaiian Gold Timber (*Bambusa vulgaris vittata*) [52]. Chung and Yu [44] carried out compression tests on two bamboo species, which are *Bambusa pervariabilis* and *Phyllostachya pubescens* [48]. Bamboo culms were used as the specimens. For *Bambusa pervariabilis*, the average ultimate compressive strength obtained is 103 MPa while the average compressive modulus of elasticity obtained is 10.3 GPa [48]. For *Phyllostachya pubescens*, the average ultimate compressive strength obtained is 134 MPa while the average compressive modulus of elasticity obtained is 9.4 GPa [48]. Chung and Yu had shown that the mechanical properties of the bamboo were best to general constructional wood [48]. On the other hand, Li also conducted compression test on bamboo [49]. However, the species of the bamboo used was unknown. Li used bamboo specimens that were of different age and that were found from various positions of the stalk. Rassiah et al. [49] has conducted the Charpy impact test on refined and coated bamboo strips. The bamboo species used is the *Gigantochloa scortechinii* [49]. The bamboo plant was trim into

plunder fibre fragments utilizing a chopper and a hand saw. Then plunders were trim into thicknesses of 1.5, 2.0, and 2.5 mm. Three regions of the bamboo plants are cut, which are inner section, middle section and outer section. The bamboo strips were then exposed to the hand lay-up operation. The laminated bamboo samples are fabricated by mixing unsaturated polyester with methyl ethyl ketone peroxide catalyst and then brushing this mixture on the bamboo strips. The Charpy impact test was carried out in accordance of ASTM D 6110 standard [49].

7.3 Fracture Toughness

The property of fracture toughness is that, which represents the quantity of stress needed to generate a crack or defect [51]. It describes how far a material can go to resist fracture at the crack. As bamboos is used in many high load structures and are exposed to wear and tear, it is essential to know its fracture properties to take the necessary precautions. Mode I and Mode II fracture properties of bamboo will be discussed here.

7.4 Mode I Fracture Properties

In Mode I fracture, the rupture surface is perpendicular to the direction of the greatest tensile loading [51, 53]. In Mode I fracture toughness, the mechanical property that will be studied is fracture toughness, K_{IC}. Liou and Lu [51] had carried out Mode I fracture test on bamboo culms of Moso bamboo (*Phyllostachys pubescence*) [53]. This study has used ASTM E399 test method, which involved arc shape bend specimens.

Amada and Untao did a throughout study on the fracture properties of 2-years old Mousou bamboo (*Phyllostachys edulis*) [52]. First of all, they have conducted Mode I fracture test on specimens from different culm. Besides that, we can also see that the fracture toughness of bamboo increases with its height.

On the other hand, Amada and Untao also conducted Mode I fracture test on the bamboo nodes. Amada and Untao suggested that this fibre made little or no contribution to the fracture properties of the node [52]. The average fracture toughness obtained for the bamboo node is 18.4 MPa \sqrt{m} , which is significantly lower when compared to the bamboo culms. Amanda and Untao have also concluded that the fracture toughness of the bamboo intersection is contributed through the parenchyma cells [52].

7.5 Mode II Fracture Properties

Mode II fracture properties involve in-plane shear loading, which is the sliding of one crack face with respect to the other in its on plane [53]. The total number of samples used in their study is 43 samples and the average Mode II fracture toughness obtained is 1303.18 J/m^2 , 1107.54 J/m^2 and 1216.06 J/m^2 , respectively with some deviations between methods. For all three methods, the bamboo height has minimal effect on the fracture toughness of the bamboo.

7.6 Effect of Moisture on the Mechanical Properties of Bamboo

Since bamboo is constantly exposed to harsh environment, such as exposure to rain and river, the result of wetness or water contented on its mechanical properties has to be properly studied. Numerous researchers have conducted test to regulate the result of moisture on the mechanical properties and all have proven that the mechanical properties of bamboo is weakened by the presence of moisture.

7.7 Tensile and Compression Properties

Lakkad and Godbole [54] have conducted an experiment that revolves around the result of water engrossment on the mechanical properties of bamboo. Three types of specimen configurations are prepared: dry; soaking in distilled water for 144 h (“wet” samples); soaking in boiling water for 2 h (“boiled” samples). For the “wet” and “boiled” bamboo samples, their weight gain are recorded from time to time to monitor water saturation level. The tensile modulus of elasticity of the specimens is dropped by 47.7% and 31.1% when immersed in distilled water for 144 h and simmered in distilled water for 2 h, respectively. On the other hand, the tensile strength of the specimens is dropped by 36.9% and 26.6% when immersed in distilled water for 144 h and simmered in distilled water for 2 h, respectively. It shows that exposing bamboo to water has drastic effects on its tensile properties. Soaking the bamboo in distilled water for long term does more damage to its mechanical properties than boiling it in distilled water in a less span of time. The bamboo fibers are not damaged by the high temperature. However, the diffusion of water within the “wet” and “boiled” bamboo samples do reduce its tensile properties. As additional water has been engrossed by the “wet” bamboo samples when compared to the “boiled” bamboo samples, their tensile properties are much reduced. In order of contraction properties, the reduction in compressive strength is more or less the same for the “wet” and “boiled” samples. The decrease in contraction power is around 50%. It is very evident that water content in bamboo can greatly decrease their tensile and compression properties. Similar

study has also been conducted by Yap et al. [48] on *Bambusa vulgaris vittata* type bamboo and practically the same decrement of the mechanical properties was found. Dorez et al. [55] reported the result of environmental aging on the tensile properties of bamboo glass fiber strengthen polymer matrix hybrid composites. The length of the glass fiber is 3 mm and the length of the bamboo fiber is 1–6 mm, which both are randomly oriented in the resultant composite plate. Dog-bone shaped specimens accompanied by dimensions of 60 mm × 12 mm × 3 mm were produced and the tensile tests are carried out in accordance of ASTM standard D639.

7.8 Thermal Properties of Bamboo

Evaluation of thermal properties of bamboo composites and apprehension of their belongings are censorious for the design of building construction. Thermal conductivity hegemonies the rates of heat transfer by utilizing the bulk material during processing to control heating and cooling processes. Material thermal censorious plays an important role in fire safety for the long-term durability of buildings. Thermal stability of medicated and unprocessed bamboo fibers was moved out utilizing a thermo gravimetric analyzer (STA7000, Hitachi). The mass varies of bamboo fiber in the % as a basis of enhancing temperature accompanied by steady rate of warming was noticed. All specimens were kept in a pan and increase the temperature from 20 to 800 °C at a rate of heating of 10 °C/min under a nitrogen surrounding.

7.9 Scanning Electron microscopy

The superficial morphologies of unprocessed and alkali-treated bamboo fibers as well as the rupture area of the bamboo fiber strengthen polymer compounds (polyester, vinyl-ester, epoxy), were investigated through scanning electron microscope TM3030 plus Benchtop Electron Microscope Hitachi, Japan. The resemblance was executed at accelerating voltages of 5–15 kV.

7.10 Flammability of Bamboo

Jobs of bamboo are not combustible as individuals expect. Even though bamboo is original substance, the obstruction to fire is not minor to cement, iron, steel. Currently bamboo jobs are familiar because of its distinctive charmer. But, most of the individuals are too disturbance regarding the capacity of fire-prevention. Everyone believes that bamboo jobs are effortless to blaze. But, that declaration is totally incorrect! Bamboo is combustible while it's chop. On the basis of the above opinion various

researchers have provided their view either through few execution tests or few differentiation accompanied by the other herbs. Nurul Zuhairah et al. [56], have introduced only method to utilize bamboo material as original fiber reinforced composites (NFRCs). The investigation was intended to find the enlarge to that of bamboo material could restore glass fiber in glass polypropylene (GPP) compounds and whether the suggested mixtures were proficient of participating, specifically in contrast to the combustibility of GPP compounds. In the field of bamboo-reinforced composites, only a very small number of researchers [57] have performed studies in flammability. However, no such investigation has been regulated on the fire performance of bamboo fabric PP composites. Most research carried out using natural fiber-glass reinforced hybrid composites has focused on physical and mechanical properties. Remarkably, flammability testing of hybrids using quantitative methods has been relatively rare as well as the prediction using Rule of Mixtures. However, no such research has been performed on flammability of bamboo-glass hybrid composites [58]. The hybrid composites, where several layers of glass in a GPP composite are replaced with bamboo fabric, may improve the flammability. Experimentation has been carried out for the thermo-physical characteristics and flammability department of poly (ethylene terephthalate) (PET) compound, containing bamboo charcoal (BC) stuffing. Outcomes represented that the amount of resistance reduced smartly but accompanied by small result on thermal conductivity, when PET was loaded accompanied by higher than bamboo charcoal. Thermo gravimetric analysis (TGA) disclosed that soaring bamboo charcoal loading was linked accompanied by a higher onset temperature of 50% humiliation ($T_{d50\%}$). However, the flammability of bamboo is under acceptable range, but it has been seen that the mixture of bamboo fabric to others, either by the method of reinforcement of composites or by using as a charcoal, gives even better result as compared to the bamboo itself. So, the central importance of bamboo fabric in flammability of these composites is the substantial contribution of bamboo fabric to the fire resistance in bamboo-glass PP composites. Nurul Zuhairah et al. [56] have mentioned in their investigation that, this was the first time for bamboo fabric used in conjunction with glass in order to increase fire resistance of the composites. So, hybridization may be useful in applications where fire resistance is important. Demand for more natural fiber materials means a reduction in glass use. A remarkable segment of the glass in GFRCs may be restored accompanied by bamboo fabric, with a positive result on fire obstruction. Hence, in near future the deduction in combustibility and the improvement in properties achieved, illustrate assurance for the mixture substances petitions.

7.11 Recycling of Bamboo

Investigations have represented that of all the constructing substances which are utilized in buildings, bamboo is the less dangerous in names of misuse as it can be reprocessed and does not have discarding complications. The radicals in bamboo support to manage ground deterioration as it forms a water wall. The highest standard

of manufacturing bamboo lyocell is that it's a 100% closed-loop revolution that secures all the chemicals, water, and everything else utilized to generate it is 100% reused and accommodated.

8 Applications of Bamboo

Bamboo, an eco-friendly substance, has a plenty of uses. The Bamboo plant belongs to the grassland ancestry called Poaceae in the subfamily of Bambusoideae. They are pine everlasting herbs, which primarily enlarge in the tropics. Similar to other grasses, they have parallel leaves, however for the bamboos particularly; their stalks are hollow and columnar. Bamboos are few of the quickest enlarging herbs on the planet, and are because of their single rhizome-dependent structure, few of herbs can enlarge up to 36 in. in a 24 h time. Few of the Bamboo enlarging in the exact states without any animal disruption they can extend up to 164 ft height and as high as 12–20 in. wide, this, moreover, does not implement to all bamboo herbs but to particular herbs.

8.1 Modern Uses of the Bamboo

Bamboo has been utilized in the constructing of roads and buildings in most of the regions of Orissa in India, other formations linked accompanied by convey such as bridges have been made utilizing bamboos in various locations of China also till date. Bamboo has been utilized to construct pretty home constructions which are not only powerful and muscular, however, long-lasting accompanied by the capability to resist rasy circumstances. Numerous holiday resorts close to see utilize Bamboos to include an artful connect to their developments and more than a billion people are determined to live in bamboo homes. The bamboo herb has for years supplied food for both animals and human beings and maximum Asian food productions include the utilize of the bamboo herb, bamboo wounds are eaten raw, cooked or utilized to form a stock, maximum Asian culinary shops even sell them in fried, dried, and canned versions, which are prepared to eat. In Japan, the bamboo is utilized as a food preservative because of its high antioxidant characteristics established in its dermis, which blocks the enlargement of bacteria. Bamboo is utilized to build attractive furniture that can too double up as decorative pieces in the home. Due to its brightness that is an outcome of the hollow place internally, bamboo stalks are often utilized for scaffolding throughout the construction of buildings and it is an economical, highly environment friendly manners of buildings.

8.2 Application of Bamboo Materials in Building Construction

Bamboo, as the primary architectural building in bamboo architecture, takes part in the load holding of construction structures. Bamboo has powerful adjustability in thickness and power and can build various compound adaption correspondingly based on the architectural building to convince the need of various building execution. On the other hand, the scientific demands of bamboo constructions are comparatively small and can effortlessly be united into municipal architectural buildings, for e.g., the combination of bamboo accompanied by ground soil, concrete and glue, etc., can support to enhancing the constructional power. As per the latest and current bamboo architecture, the important technique of bamboo architecture lies in the intersection position in the middle of main constructional components consisting tension and stress. The power, stiffness and solidity of intersections primarily are based on the junction power in the middle of construction elements of the building. Hence, the enhancing development of relationship construction has showed additional subscriptions to the diversification of bamboo architecture.

9 Conclusions

As, bamboo is a versatile raw material for social, economic and cultural point of view, it has been compared with steel through which it has been noticed that bamboo is much cheaper than steel even, bamboo properties like high tensile, flexibility, light weight, toughness is much better than the other building materials. In the present review work an overview of bamboo material has been studied by focusing its origin, historical background, specification, applications and different properties, like mechanical, thermal, flammability and recycling. On account of different properties of bamboo detailed study following major findings have been concluded:

- The characteristics of bamboo and its coated outcomes verify to its potential in switching wood. Use of bamboo has enhanced remarkably in the wood and wood outcome industries, accompanied by sufficient regenerating in maximum operating firms in the section.
- The mechanical properties of bamboo are weakening by the presence of moisture.
- The fracture toughness of bamboo increases with its height.
- Compression tests on two bamboo species, which are *Bambusa pervariabilis* and *Phyllostachys pubescens*. Bamboo culms were used as the specimens. For *Bambusa pervariabilis*, the average ultimate compressive strength has been found to 103 MPa while the average compressive modulus of elasticity obtained was 10.3 GPa.
- For *Phyllostachys pubescens*, the average ultimate compressive strength obtained was found to 134 MPa while the average compressive modulus of elasticity obtained was 9.4 GPa.

- It had been found that the mechanical properties of the bamboo are higher to familiar constructional wood.
- As, the bamboo fibers are not damaged by the high temperature, the diffusion of water into the “wet” and “boiled” bamboo specimens do reduce its tensile properties.
- The planes structure of unprocessed and alkali-treated bamboo fibers as well as the rupture plane of the bamboo fiber reinforced polymer compounds (epoxy, polyester, vinyl ester), were investigated by scanning electron microscope TM3030 plus Bench top Electron Microscope Hitachi, Japan. The imaging was executed at accelerating voltages of 5–15 kV.
- However, the flammability of bamboo is under acceptable range, but it has been seen that the mixture of bamboo fabric to others, either by the method of reinforcement of composites or by using as a charcoal, gives even better result as compared to the bamboo itself. So, the central importance of bamboo fabric in flammability of these composites is the substantial contribution of bamboo fabric to the fire resistance in bamboo-glass PP composites.
- Hybridization may be useful in applications where fire resistance is important. Demand for more natural fiber materials means a reduction in glass use. A notable section of the glass in GFRCs may be changed accompanied by bamboo material, with a positive result on fire obstruction.
- In near future the deduction in combustibility and the improvement in characteristics attained, illustrate assurance for the mixture substance petitions.

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