# Teak (*Tectona grandis* L.f.): a preferred timber for shipbuilding in India as evidenced from shipwrecks

**Sila Tripati[1,*], S. R. Shukla[2], S. Shashikala[2] and Areef Sardar[1]**

[1]CSIR-National Institute of Oceanography, Dona Paula, Goa 403 004, India
[2]Wood Properties and Uses Division, Institute of Wood Science and Technology, Malleswaram, Bengaluru 560 003, India

**One of the greatest achievements of man is the design and development of a variety of watercraft suitable for marine and riverine purposes and safer for the environment. From ancient times, timber was the main component for the construction of these crafts, until it was replaced by iron/steel. As the size of the vessels increased to accommodate more cargo and overseas trade became more frequent, superior quality timber was used in the construction of vessels. Among the timbers used, teak was mostly preferred for building boats and ships. Many ships have been explored and excavated, and the timber used has been identified, but a detailed microstructural analysis has not been presented. The *Cara Merchant* or *Quedagh Merchant* ship, built in Surat, Gujarat, India was pirated by Captain Kidd, and subsequently wrecked off the southeast coast of the Dominican Republic in 1699. Indiana University, USA, carried out exploration to locate *Cara Merchant*. This communication presents a comparative study of the anatomical analysis of the microstructure of a wood sample with the wood from the wrecked *Cara Merchant*. This study is an attempt to support the use of teak in boat and shipbuilding as mentioned in the literature.**

**Keywords:** Scanning electron microscope, shipbuilding, shipwreck, teak, wood anatomy.

INDIA has contributed significantly to world culture in the field of science, technology, culture and philosophy. One of the greatest achievements of man was the invention of watercraft made of reeds, logs and skins, which were used from prehistoric times. A variety of traditional watercraft were designed and developed according to the topography and nature of the seabed of the region; locally available suitable timber was used for both inland and sea craft. Over a period of time, many changes were noticed in the boat and shipbuilding techniques, and wood became the most widely accepted material for hull construction. This practice continued until the last century when timber was partly replaced by iron/steel and fibre/composite materials.

From ancient times, timber has been one of the most valuable and versatile raw materials playing a vital role in the economic and industrial development of a nation. Each type of timber has its own distinctive features depending on whether it belongs to the hardwood or softwood group. Different wood species also differ considerably in their anatomical structure and show a remarkably wide range of variations in physical and mechanical properties such as colour, texture, grain, density, strength, stiffness, hardness, etc.[1,2]. The variations in the microstructure of different wood species mostly depend on the proportions, size and distribution of various cell types such as vessels, fibres, parenchyma, rays, including gum canals, ripple marks, etc.[1]. Based on internal structure, properties and performance, timber is put to a variety of uses.

Generally, a timber species is not chosen for a given application, merely on account of its easy availability, cheapcost and other considerations, but also due to its quality, durability and performance. In the Indian subcontinent, the earliest evidence of boat building comes from the Indus Valley region and representations are found on seals, clay models, pottery and potsherds. Timbers such as deodar, sal and teak, which was used for construction of boats, houses, carts, etc. have been recorded from Harappan sites[3,4]. Information on the construction of boats and ships, their sizes and designs, different parts of boats, usage, etc. is also found in the literature, and was recovered from archaeological excavations both inland and underwater. However, except for a few studies, there is no reference to the variety of timber species used for boat and shipbuilding[5]. There is no clear mention of the type of timber used for this purpose, which may be validated from the remains of boats and ships found during inshore or offshore explorations.

Shipwreck studies shed light on historical contacts or linkages. Analysis of timber used in a ship also helps indicate its origin, and recognizing the species is important in the identification of the shipwreck. Till date, very few wooden vessels have been explored in the Indian waters (Figure 1). On the contrary, many shipwrecks have been explored and excavated in foreign waters. Analysis of timber of some of the shipwrecks showed that those built in India were mostly made using seaworthy wood species such as teak, sal, sissoo, anjili, etc.[6–13].

Over the centuries, literature evidences, and traveller's and shipwright's accounts have also suggested that teak is highly suitable for shipbuilding because of its superior quality. However, not many attempts have been made to confirm the use of teak for shipbuilding as mentioned in the literature. This communication deals with anatomical studies, through thin section, of wood samples from the shipwrecks as obtained from a long-established, old timer ship manufacturer located in Surat, Gujarat, India. The analysis of wood samples found from excavated shipwrecks in foreign waters has been compared and consolidated to confirm the statements made on teak in the literature.

Many shipwrecks have been excavated in different parts of the world, but timber species used in the

*For correspondence. (e-mail: sila@nio.org)

construction of these ships have not been analysed anatomically at microstructure level. The wood samples of Dang forest collected from the Wadia family of Surat (who have been involved in shipbuilding since 1781), were subjected to detailed microstructural analysis. Two samples were observed for various anatomical properties to confirm the type of wood used in the construction of boats and ships. Standard laboratory procedures were followed for sectioning of wood samples. Small wooden blocks were prepared and boiled in water to make thin sections of about 20–25 µm thickness using Reichert sliding microtome. Micro-slides were prepared for cross-section, tangential–longitudinal (TL) and radial–longitudinal (RL) sections. Part of the remaining sample was used for maceration[14]. The samples were observed with hand lens (10×) and described for their macroscopic features. Observation of sections for characterization and data on vessel, fibre and ray morphology were collected from Wadia family of Surat analysed at IWST, Bengaluru using Leica microscope (model Laborlux POL12S) connected to an image analysis system (Quantimet 500 MC). The basis of identification of wood samples was a combination of physical features, gross structure and anatomical characters. A few representative photomicrographs presented here were captured using image analysis system.

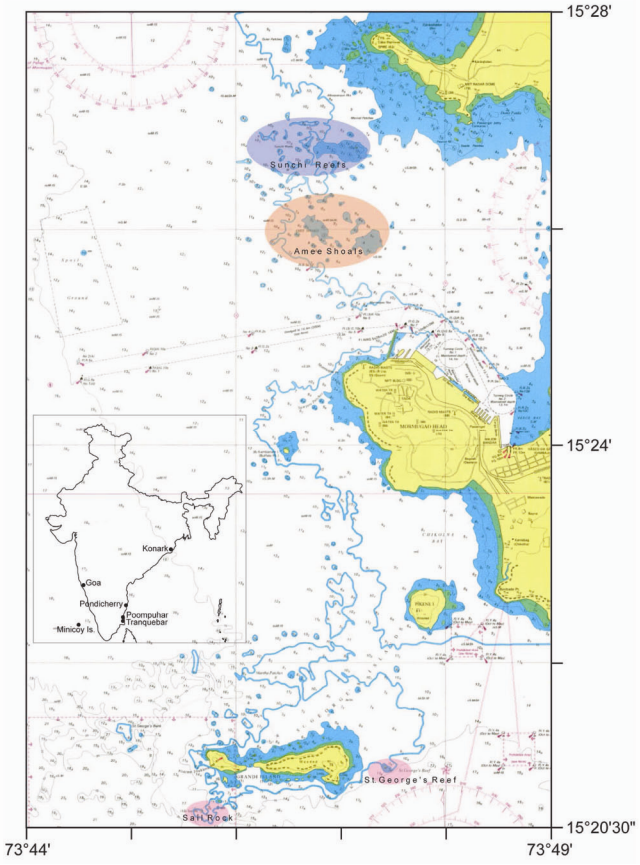


**Figure 1.** Location of shipwrecks explored in the Indian waters.

Scanning electron microscope (SEM) studies were carried out at higher magnification for observation and comparison of the microstructure of wood samples. SEM analysis of timber used in the *Quedagh Merchant*, built in Surat[15], was considered for comparison with the wood samples of the present study. Thick sections of 10–12 mm were prepared from the oven-dried wooden blocks and cleaned with ethanol using an ultrasonic cleaner. The sections were mounted on clean, dry slides and coated with a thin gold layer. These sections were observed under high resolution using SEM (JEOL; model 5800LV), and detailed anatomical features were recorded.

Wood samples, collected from the Wadia family, were observed for various anatomical properties. Figure 2 shows the microstructure of the wood samples. The cross-section illustrates that the wood sample is ring-porous, having distinct growth rings and delimited by large earlywood vessels embedded in parenchymatous tissues, and mostly solitary, oval in outline and gradually becoming smaller towards the latewood (Figure 2 *a*). Latewood vessels are moderately large to small, mostly solitary and round-to-oval in shape. Parenchyma is para-tracheal, delimiting the growth rings. Figure 2 *b* shows a RL

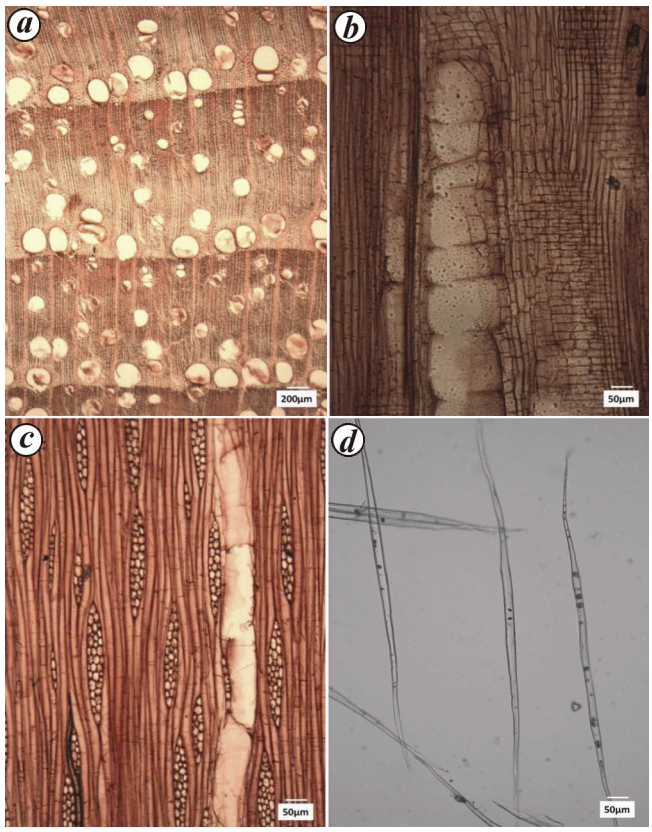


**Figure 2.** Anatomical photomicrographs of teak collected from Surat, Gujarat, India. ***a***, Cross-section showing large earlywood pores delimited by a line of parenchyma and smaller latewood vessels. ***b***, Radial section showing simple perforation plates, parenchyma strands and rays. ***c***, Tangential section showing uni- and multi-seriate rays and septate fibres. ***d***, Fibres as seen in the macerated material.

section exhibiting procumbent ray cells and ray-vessel pitting in the wood sample. The TL section of the wood sample (Figure 2 *c*) exhibits predominant multi-seriate rays, inter-vessel pits and septate fibres. A few vasicentric tracheids are also seen in macerated material. Figure 2 *d* shows septate to non-septate fibres containing silica in the macerated material. Table 1 shows the average values and range of different anatomical features of the wood samples analysed in the present study. A combination of characteristics like ring porosity, vestured pits, simple perforation plates, septate to non-septate fibres, and multi-seriate rays, and other quantitative features of vessels, rays and fibres suggest that the samples belong to teak[2,16].

**Table 1.** Mean and range of values of anatomical properties of teak samples

| Property (μm) | Mean value (± SD) | Range of values | |
|---|---|---|---|
| | | Minimum | Maximum |
| Fibre length | 1210 ± 67 | 1067 | 1329 |
| Fibre diameter | 24.43 ± 1.60 | 21.46 | 27.25 |
| Fibre lumen diameter | 16.39 ± 1.74 | 12.77 | 20.87 |
| Fibre wall thickness | 8.05 ± 0.98 | 6.38 | 9.86 |
| Early wood vessel diameter | 255 ± 21 | 208 | 286 |
| Latewood vessel diameter | 126 ± 26 | 84 | 176 |
| Ray height, uni-seriate | 129 ± 38 | 88 | 224 |
| Ray height, multi-seriate | 287 ± 66 | 175 | 437 |
| Ray width, uni-seriate | 14 ± 2 | 10.5 | 18 |
| Ray width, multi-seriate | 37 ± 8 | 25 | 59 |
| Inter-vessel pits | 5.55 ± 0.50 | 4.56 | 6.43 |

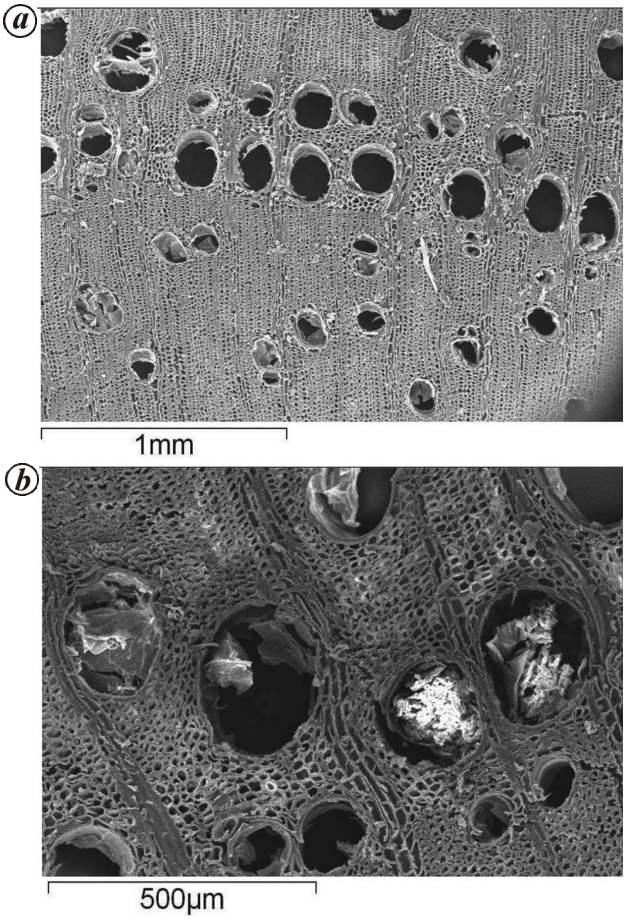


**Figure 3.** Scanning electron photomicrographs of cross-section of teak samples collected from Surat: ***a***, Lower magnification; ***b***, higher magnification.

Figure 3 shows the cross-section of wood samples collected from Surat as observed under SEM. Distinct growth rings are present and the wood is ring-porous. One to two rows of earlywood pores are embedded in a band of parenchymatous tissue. The earlywood pores are large, solitary, in radial multiples of two and occluded with deposits (Figure 3 *b*). The latewood pores are moderately small to moderately large, solitary and in radial multiples of two. Rays are moderately broad. Crystals are not observed.

Figure 4 shows the scanning electron photomicrographs of cross-section of teak samples of *Cara Merchant* or *Quedagh Merchant* shipwreck. The cross-section shows xylem in the form of a cylinder. Vessels are arranged in semi-ring-porous arrangement with thin-walled tyloses and silica present as scaly inner lining. Axial parenchyma is exclusively paratracheal. Rays, five or more cells wide, are composed of a single cell type (homocellular)[17]. It may be noticed that both the Wadia sample and the *Cara Merchant/Quedagh Merchant* sample exhibited identical microstructure as confirmed by SEM analysis of both samples. Earlier studies of wood samples collected from shipwrecks off Goa coast, and Minicoy Island off Lakshadweep show the use of *Tectona grandis* in various parts of boat/ship construction[18,19]. In this context, it is to be mentioned that for centuries, teak has been one of the preferred timber for boat and ship-building in our country.

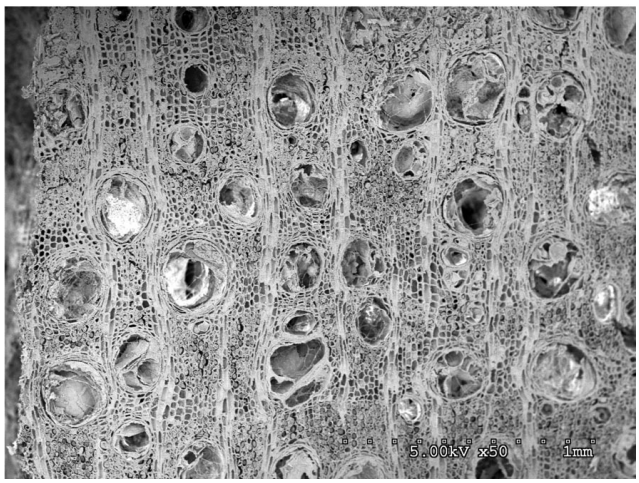


**Figure 4.** Scanning electron photomicrograph of cross-section of teakwood samples of *Cara Merchant* or *Quedagh Merchant* shipwreck (Courtesy: Charles Beeker, Indiana University, USA).

Considering the length of maritime history of India, and the shipwreck information available in archival sources, a limited number of shipwrecks have been explored in the country. From the commencement of maritime archaeological studies in Indian waters, until now, five shipwrecks (Sunchi Reef, St George's Reef, Amee Shoals, Sail Rock and Grande Island) off Goa[20], four Minicoy Island[21], one each at Suheli Par and Bangaram Island[22] off Lakshadweep Islands and one each off Poompuhar in Tamil Nadu[23] and Konark coast, Odisha, have been explored (Figure 1). A 2 m long single timber was found during exploration of the St George's Reef shipwreck site. One end is well preserved, while woodborers have destroyed the other end. Chisel marks are visible on the timber. This timber survived because it was buried under sediment. The anatomical analysis of the timber shows that it belongs to the *Lagerstroemia lanceolata* species, for which the trade name is benteak[20]. Timber remains were found on the doorframe hinge and door latch of shipwrecks in Minicoy waters. Anatomical analysis of both the samples confirmed that these belong to teak (Figure 5). Similarly, an admiralty type of iron anchor with wooden stock, datable to the Portuguese period, was recovered off Aguada, Goa. The anatomy of the wooden stock (Figure 6) indicates that it is teak[18]. During explorations in 8–10 m water depth, three boilers, cabin and frames of a shipwreck were noticed off the Konark coast. As a major portion of the boilers is buried in the seabed because of shallow water depth and high energy zone, nothing has been salvaged from the shipwreck. Marathe *et al.*[24] have studied the buried rafters collected from the basin of Jog River, Ratnagiri district, Maharashtra. The rafters were made of *T. grandis* and radiocarbon dating gave an age of AD 960 ± 63.

Several Indian-built ships have been wrecked in foreign waters, but scanty information is available on them; very few have been located, explored and identified. Among these, exploration of the 9th century AD Belitung shipwreck in Indonesian waters provided direct evidence of overseas trade between China and India/Arabia. The main cargo of the ship was Chinese ware (Changsha ware). A detailed study of the timber showed that teak was mostly used for beams and other timber species were used for the construction of different parts of the ship. Further, it was suggested that the ship was either built in India or Indian timber was exported to the Middle East for its construction. It could even have been an Indian ship supplying the Middle East, or an Indian-built ship owned by the Arabs[25,26]. Teak, shisham and Indian rosewood (*Dalbergia latifolia*) were the main timber used in the construction of hull, frames and planking of the *Sydney Cove*, 1797; all these are obtainable from the vicinity of the Bay of Bengal. The wooden stock of the iron anchor of the *Sydney Cove* was also made of teak[27].

Shipwreck history is as old as the maritime history of India; however no shipwreck records are available in the

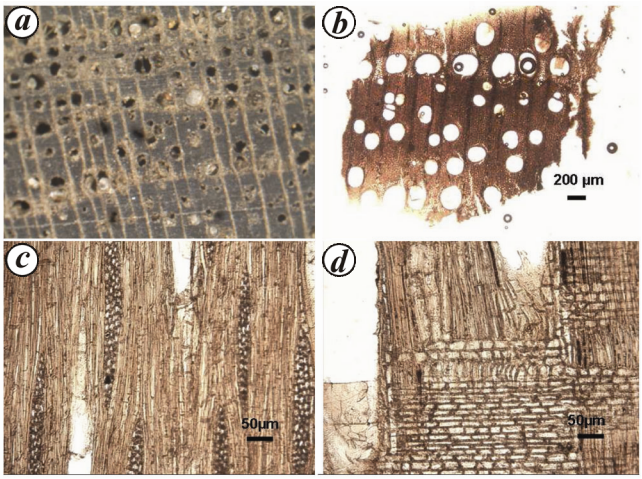


**Figure 5.** Anatomical analysis of timber remains found on doorframe hinge and door latch collected from steam engine shipwreck of Minicoy Island, Lakshadweep, India. ***a***, End grain pattern showing ring porosity and growth rings as seen under stereo zoom microscope (20×). ***b***, Cross-section showing gradual transition from early wood to latewood: larger vessels in early wood and smaller vessels in latewood. ***c***, Tangential–longitudinal section showing predominant multi-seriate and homocellular rays, inter-vessel pits and septate fibres. ***d***, Radial–longitudinal section showing procumbent ray cells and ray-vessel pitting.

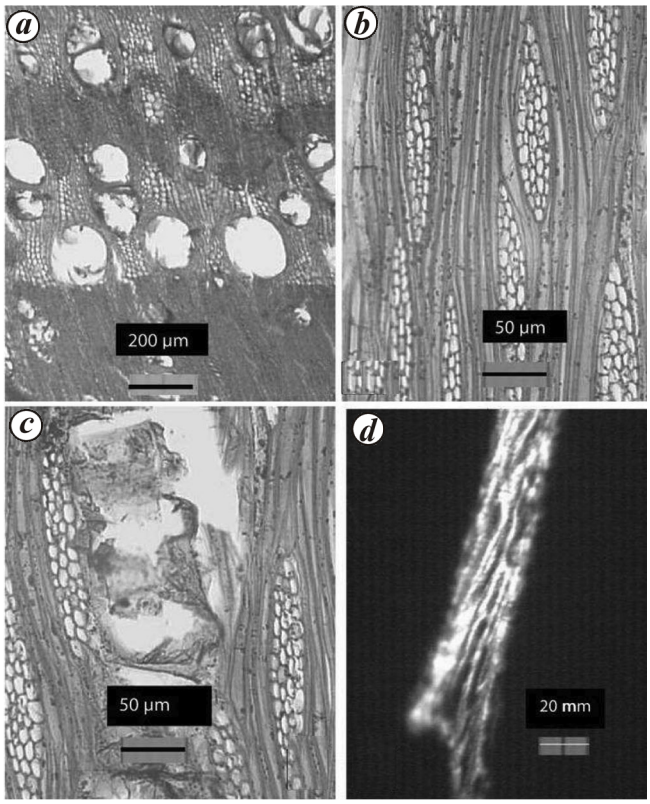


**Figure 6.** Anatomical analysis of timber of wooden stock from Aguada Bay teakwood: ***a***, cross-section; ***b***, ***c***, tangential–longitudinal section; ***d***, fibre in polarized light.

country prior to the European period. Till date information on 215 shipwrecks, both Indian and foreign built, in Indian waters has been collected from various archives of India. Attempts have been made since 1986, along the east and west coasts of India, to explore and document shipwrecks. Among these, the shipwreck off the St George's Reef, Goa, showed the use of teak. Two admiralty long iron anchors with wooden stocks were retrieved off Aguada in Goa waters. Anatomical analysis of timber confirmed that the wooden stock was made of *T. grandis*[18], *Terminalia* spp. and *Phoebe* spp.[28]. *T. grandis* is found in India and South Asia, whereas *Terminalia* spp. and *Phoebe* spp. are found in the tropics of the World and in the Indo-Malayan region, Pacific Islands, tropical America and the West Indies.

In 1698, the *Cara Merchant* or *Quedagh Merchant*, a Surat-built Indian merchant vessel, was captured off the Indian coast by Captain William Kidd, a pirate, who sailed the ship to different places. Finally, it was abandoned at Catalina Island off the southeastern coast of Hispaniola en route to New England in 1699. Since then, the vessel had remained lost in its watery grave. The Government of the Dominican Republic and Indiana University, USA, jointly carried out exploration to locate and excavate the *Cara Merchant*. Important findings during the exploration included a total of 26 cannons, a number of iron anchors and several tonnes of scrap iron. According to Kidd, the *Quedagh Merchant* was 'built at Surrat' (Surat, India) and timber from Dang forests (near Surat) was used for its construction. Teak has been recognized as one of the finest timbers for naval purposes due to its high resistance to water and worms'.

In case of the origin of the wooden structural remains of the *Quedagh Merchant*, historical documentation again coincides with the archaeological records. The microstructure of the wood sample provided by the Wadia family and the wood used in the *Cara Merchant* was comparable as observed under high-resolution SEM. A comparison of microstructure (Figures 3 and 4) confirmed that *Cara Merchant* was made of teak and built at Surat. Analysis of timber obtained from the shipwreck showed that in addition to teak, other timber species were also used in shipbuilding. But, teak was preferred over the others because of its superior quality.

The question arises as to why teak was preferred for shipbuilding over oak and other timber species by the Europeans? Important characteristics of teak as one of the preferred timbers for boat and shipbuilding, construction work, furniture, veneer, carving, turnings, handicrafts, etc. are its texture, shiny colour, weather resistance and natural durability[2]. Efforts were made in the past to find suitable and adequate substitutes for teak, but many of them did not have the same quality and always fell short of being as useful and efficient as teak. In fact, it has been shown that even when iron/steel was introduced in the shipbuilding industry; it could not replace the high demand for teak. Teak is generally considered superior to other wood species because once it is seasoned properly, defects such as end cracks, surface checks, splits, twist, etc. will not occur. Despite its superior strength, teakwood is not too heavy and has great elasticity, making it a favourite type of wood to work with. Teakwood contains a high level of silica (up to 1.4%), which has a pronounced blunting effect on cutting edges of woodworking tools. Despite its natural oils, teakwood usually glues and finishes well[2]. It also takes on a beautiful polish when finished, because it contains natural oils.

The heartwood of teak possesses high decay resistance in terrestrial conditions and is very durable. It is also reported that quinones and their derivatives such as tectoquinone, lapachol, desoxylapachol and its isomer, found in abundance in the extractives, are responsible for the anti-termite and anti-fungal activities of teakwood due to their toxicity against wood-attacking bio-organisms[16]. Only certain types of timber possess a great degree of resistance owing to the presence of various natural substances such as resinous materials, gummy deposits, oils, alkaloids, silica, etc. The resistance against shipworm shown by teak may be due to the presence of oils and silica[29]. Teak is, however, moderately resistant to powder-post beetles and resistant but not immune to marine borer attack[30]. Muller[31] has discussed the marine durability of different wood species used for shipbuilding against shipworms (Teredinidae), which are found mostly in coastal regions at temperate and tropical latitudes. Further, he has stated that infestation of timber by shipworms can be prevented, or at least impeded using shipworm-resistant timber or effective wood protection. It is also believed that there are still many wooden shipwrecks of ancient times buried under the sea floor. Here the timber is not infested by shipworms and is therefore in a relatively safe environment. According to Sen *et al.*[32], hardwood species are more durable in the marine environment compared with soft wood species, because they resist boring organisms. Muller's[31] observations have been confirmed in the case of an iron anchor with wooden stock found off Aguada Bay, Goa, one end of wooden stock being affected by shipworms, while the other end buried in the seabed[18].

Regarding the superior properties of teak and its usefulness for shipbuilding, several observations were made by shipwrights, merchants, travellers and others. 'The excellence of teak for the purpose of shipbuilding and its durability are too well known to require any description; although it must be observed that Pegue teak is not reckoned equal to what grows on the Malabar Coast, and near Surat….' Robert Seppings also noted the quality of teak and reported that 'Teak is the most durable, but differs very much in quality.' He continued to designate Malabar northern teak as the most valuable timber in the world for ship-building. In the 18th and 19th centuries, many treatises were published on oak and teak and on their quality,

durability, etc. One among these was authored by Money[33], who mentioned that because oak contains lignic acid, once it comes in contact with iron, it increases the rate of corrosion and decay of iron, thus reducing the endurance of the ship. Iron was used extensively in the construction of vessels because of cost-effectiveness and easy availability. In the case of teak, it abounds in oleaginous particles, which protect iron from corrosion. It was also well known that Malabar teak is one quarter less in weight than oak, and neither splits nor is hazardous to metals like oak. Furthermore, a ship built of teak lasts for more than 50–60 years. Additionally, teak does not splinter to the extent that oak does. Therefore, teak was preferred in shipbuilding compared to other timber species, and was traded for shipbuilding in the Indian Ocean countries for several centuries[34].


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