Boat Building Materials with Special Reference to Environmental Impacts

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According to FAO (2004), world fishing fleet consists of 4 million vessels in which 2.7 million were open boats and remaining were traditional crafts. Most of the decked boats were mechanized but only one third of the undecked fishing boats were motorized while traditional crafts were operated by sail and oars. From the time immemorial, fishing vessels has played a pivotal role in maritime operations. They fulfill the demand of fisheries sector to a great extent. The common materials used for the boat construction in India include wood, glass/fibre reinforced plastic, aluminium, steel, plywood, ferrocement etc. While selecting a material for boat construction some basic factors to be considered are type, size, speed, shape of the vessel, availability and suitability of the material and economic and environmental viability. The performance and efficiency of a boat is directly dependent on the choice of the boat building material which also has a direct impact on the environment. By taking these facts into account, a boat designer can select the best possible alternative for building a boat of high efficiency and durability. At present the larger class of vessels are made of steel while vessels belonging to medium and lower category mostly use wood for construction. Fiberglass, ferrocement and aluminium are the new substitutes for conventional boat building material as these can improve the lifespan of the crafts. However, traditional crafts still play a vital role in this era. This chapter gives a brief idea on the common boat building materials and their impacts on the environment.

Wood

From ancient times, the use of wood and the value of the forest were improved significantly as the population of humans and their economies grew. Wood has been used for various marine constructional purposes due to its excellent properties like buoyancy, workability, strength, elasticity, durability, heaviness (480-624 kg m^{-3} at 12% moisture content), load-bearing capacity, treatability, nail holding power, strength to weight ratio and poor transmission of heat. Reusable and recyclable natures are some of the added properties of wood which might have attracted the boat builders for its application in the boat building sector. Normally before boat construction, wood is air seasoned and the moisture is reduced below 15% making it suitable for the purpose.

Many of the motorized and non-motorized crafts in India are made with wood. According to FAO (2015), India has 70.7 million hectares of forest land and around 2000 timber species in which about 59 species of timber are used in the construction of fishing crafts in India. Timber species which are in good demand for boat building includes *Artocarpus hirsutus* (Aini), *Calophyllum inophyllum* (Punna), *Hopea parviflora* (Iron wood), *Stroemia lanceolata* (Venthekku), *Mangifera indica* (Mango), *Melia composita* (Malabar neem), *Pterocarpus dalbergioides* (Paduak), *Pterocarpus marsupium* (Venga), *Shorea robusta* (Sal), *Xylia xylocarpa* (Irul), etc. (Santhakumaran and Jain, 1986).

Even though wood is a favoured material for the boat building sector, the hygroscopic nature makes it susceptible to bio-deterioration. The biotic and abiotic agents cause deterioration and eventually reduce the life span of the wooden crafts.

The use of preservatives protects the wood from the attack of fungal decay, harmful insects and marine borers by applying selected chemicals as wood preservatives. Proper seasoning and preservative treatment extend the service life of timber by 3 to 5 times and also it helps in proper utilization of timber and conservation of forests. Hence, the durability or the life of wooden crafts can be increased by the application of preservatives. The degree of protection obtained depends on the kind of preservative used and achieving proper penetration and retention of chemicals. In ancient times, traditional fishermen used sardine oil, cashew nut shell liquid, neem oil etc. as natural preservatives for increasing the life span of wooden boats. Even though the traditional preservatives are of natural origin, they are not much efficient due to its less penetration and retention into the wood. Short term retention of traditional preservatives necessitates the frequent maintenance procedure and consequently increased the operational cost. This leads to the introduction of chemical preservatives such as chromated copper arsenate (CCA), copper chrome boron (CCB), acid copper chromate (ACC) etc. in the boat building sector.

The main objective of wood preservation is to introduce the preservative into the wood so that a deep continuous layer of treated wood contains sufficient preservative to prevent decay and insect attack (FAO, 1986), and thereby enhances the quality and shelf life of the wood. Preservatives should possess two criteria that they must provide the desired wood protection in the intended end-use and also it should be environment-friendly. Presence of arsenic and chromium in many preservatives was of great concern to the environmentalists due to the bioaccumulation in the aquatic environment. One of the important areas of research was finding an alternative and eco-friendly substitute for synthetic preservatives like CCA. As a result, novel preservative like CCB becomes popular. Nowadays, studies are going on to incorporate nano compounds to the preservatives to increase the efficiency of preservatives and to reduce the environmental impacts.

In backwaters and reservoirs of India, basket boats/coracles made of bamboo are used since long. It is made by bamboo splits weaved to form basket of good strength. The cost of construction of bamboo boat/coracles are comparatively lower than other material of the same capacity. Bamboo preservation can be done in green and dry condition. Freshly cut culms are immersed in concentrated water-borne preservatives (5-10%) for one to two weeks. Dry bamboo can be treated with oil type solvent preservatives.

Plywood

Marine plywood is extensively used for marine vessels construction due to its commercial feasibility, high economical viability and relatively low damage in aquatic conditions. Marine plywood is prepared by gluing together a number of thin veneers of wood using a waterproof adhesive such as epoxy or phenol resorcinol. The wooden plywoods are bonded under high temperature and pressure with phenolic resin glue. Best quality marine grade plywood should have atleast 5 layers of veneers. The marine plywood is having strength-to-weight ratio. The adjacent veneers are kept in such a way that the grain direction is in right angles to each other.

The most common preservative for plywood used in boat construction is chromated copper arsenic (CCA). After the preservative treatment, the panels are re-dried to a moisture content of 18%. The kiln drying method is preferred so as to minimize the development of bends and cracks. Many uses of plywood in boats involve laminating fiberglass over a plywood boat component. The fiber glass coating protects the underlying plywood from abrasion and wear during landing and launching of boats. Marine plywood boats can ensure protection in severe conditions if it is made of durable or treated veneers.

Fibre reinforced plastics/FRP

Fibre reinforced plastics or FRP is also known as Glass reinforced plastic/GRP. The usage of FRP as a boat building material is flourished because of its low production cost and anticorrosive property. It is also easy and simple to fabricate. The main material components of FRP are the reinforcing agents like glass fibre in the form of thin fibre and a plastic resin capable of impregnating fibres. For the construction of FRP boat, the primary requirement is a mould.

The most popular reinforcement used is a form of glass processed into filaments which are then chopped and supplied in rolls. The thickness depends on the weight of the glass in grams per square meter. The two main types of glass fibres available in the market are "chopped strand mat" and "woven roving". The chopped strand mat (CSM) is made up of long fibre glass strands that are randomly oriented and held together with a binder glue. These are available in fabric form as rolls or in small folded packages with varying thickness. This material is specified by weight in which 300, 450, 600 and 900 g/m^2 are popular weights of CSM. The boat builder purchases it in rolls of 30–35 kg which are about 1 m in width. Woven roving (WR) is made from continuous glass fibre roving to increase strength and stiffness of the laminate which is sandwiched between layers of fibre glass mat. The greater strength of laminate can be achieved by using such woven glass mats.
Resin is the unsaturated polyester. Polyester resin is the main type used in the boatbuilding industry worldwide. It has good compressive strength properties but has low rigidity, tensile strength and impact strength which necessitates reinforcement with fibre glass. "Unsaturated" polyester resin is the more appropriate term for the liquid state in which it is supplied. When cured to the solid-state during the laminating process it becomes "saturated". Terylene is another example of saturated polyester resin and is a plastic and non-organic material. There are two main types of resins - "laminating" and "gelcoat". The former is a translucent liquid of various pale colours. The latter is a more viscous liquid both with a strong smell of styrene which is a characteristic of resin. The difference is in the use where the gel coat is applied directly to the mould without reinforcement and provides a smooth, coloured finish to the outside of the hull while the laminating resin provides the matrix within which the reinforcement is bedded.
Properties to be considered for boat building lay-up resin are resistance to water absorption, resistance to ultra-violet radiation and weathering, reaction to and from other liquids and solids adhesive qualities and its strength.

A catalyst changes the monomeric unsaturated polyester resin to a polymeric saturated resin that is, to a harder state, by the production of an exothermic reaction and will cure the resin. The resin is activated by a catalyst. The accelerator governs the speed of the reaction and without the catalyst, the accelerator does not affect on resin. Accelerator normally comes as two chemicals a purple liquid (Cobalt Naphthenate) is usually offered for use with Methyl Ethyl Ketone Peroxide

(MEKP). Accelerator and catalyst must never be mixed directly together as they can cause an explosion. The flashpoint for both can be as low as 20°C.

Twenty years is often quoted as the lifespan of an FRP vessel. However, there are many vessels older than this still very sound and in service. It is also obvious that a FRP pleasure boat which is well maintained and rarely used will have a longer service life than an FRP trawler in daily use and repaired only when something breaks. The fact is that an FRP trawler is more likely to become worn out through rough handling, lack of maintenance and breakages than any sudden structural failure of the hull laminate after a fixed period.

Aluminium

Aluminium is selected as a boat building material due to its lightweight with high strength, durability and easiness to repair. Since it is lightweight, it has more carrying capacity and greater speed. The elasticity of modulus is 6960 kg/mm^2 with high impact resistance. Aluminium is a corrosion-resistant material due to the production of a surface film of aluminium oxide. This oxide film thickens with time and when scratched a new protective film is built up. Pure Al containing 99.5% or more and minimal amount of silicon and iron has the highest corrosion resistance of all Al alloys. As this is too soft for application aluminum is alloyed with Mg, Mn, and silicon for marine application. The higher the Mg content in marine Al, higher the strength and the upper limit of Mg content is 5.5 % both from a corrosion point of view and from the workability point of view. Aluminium boats cost more for the fabrication but painting is not essential for these boats except antifouling paints. Antifouling paints should be carefully selected and it should not contain mercury because it destroys aluminium by forming an amalgam. Aluminium pieces are joined by the welding process where heating during the process partially reduces the strength and hence care should be taken. Attention must be given during the installation of electric circuits to avoid currents. The scrap value of aluminium is more.

The ultimate tensile strength of marine Al ranges from 31,000 - 48,000 psi. the elastic modulus for Al is about 1/3 that of steel. Al has greater impact resistance than steel. Al is non-sparking and non-magnetic. The co-efficient of thermal expansion of Al is about twice that of steel. Al has high heat reflectivity- 90 % as compared to 50 % for steel thus Al will emit only 10 % of the heat from the sun while steel emits 50 %. Insulation and refrigeration requirements are smaller in fish holds. Al is much more hygienic than steel Al has more thermal conductivity, 3 to 5 times more than steel depending on materials in consideration and therefore uniform distribution of temperature takes place faster in aluminium fish holds.

The use of aluminium for fishing craft construction offers a number of advantages that includes improved stability, reduced displacement and therefore improved maneuverability and increased cargo carrying capacity, increased speed and increasing operating range, decreased engine size, decreased fuel consumption, reduced maintenance therefore less idle time.

Ferrocement

Ferrocement is a combination of wire mesh impregnated within mortar of fine sand and cement. The main difference between ferro-cement and other forms of reinforced concrete is in the use of a fine-grained aggregate and fine meshed reinforcement in a thin shell structure. The fine ingredients give increased flexural and shear strength, increased specific surface, improved tensile bonding capacity, crack inhibition due to high proportion of small diameter wires in mesh and resistance to corrosion due to restriction of crack widths below critical values above which moisture could enter the shell structure. The strength of ferrocement is related to the weight and distribution of the steel reinforcement. Cement used are of two types- Type II Portland and V rapid hardening containing not more than 10% tricalcium aluminate. Sand having quartzite with grain size more than 2 mm is used. Additives are used to keep the water content low. Lignosulphates are used as additives. The advantages of ferrocement are high flexural strength, resistance to corrosion, high surface area and it can be built without any skilled labour. Raw materials are easily available and cost of construction is less than timber and steel.

Steel content is the weight of steel per unit volume of ferrocement element, including rods, mesh and mortar. The minimum recommended steel content is 380 kg/m^3 while the maximum is 650 kg/m^3. The steel content expressed as percentage steel area in the cross section of the ferrocement element is in the range of 2.0% - 6.5%. Specific surface measures the dispersion and fineness of the meshes and their ability to control cracking. The total surface area of the mesh divided by the volume of the ferro cement element containing it is in the range 1.8 - 3.0 cm^2 /cm^3.
The ability to build hull, decks, bulkheads, floors and engine bearers, fish tanks and bulwarks in one piece resulting in a monolithic structure of immense strength which actually increases with age is an important advantage of ferrocement. Ferrocement craft can be built without highly skilled labour. No expensive plant is needed as in the case of steel construction and to a lesser extent with timber construction. It is not necessary to use a mould for ferrocement construction as in the case of building with FRP as no temperature control is necessary. Local manufacturing can be done without sophisticated facilities. The raw materials necessary for ferrocement construction are easily available in most countries. FRP raw materials are relatively expensive and requires storage facilities. Ferrocement hull costs 20 - 25% less than a similar hull in timber or steel. Overall saving may not be more than 4 - 7%. Unlike steel it is immune to rust and corrosion and will not rot like timber. It is resistant to marine borers. Ferrocement has proven aging qualities. No painting required except to enhance appearance. Because of mesh reinforcement, it will have tensile strength in all directions. The tensile strength in wood is reduced due to numerous fastenings whereas ferrocement do not have any fastenings. Compressive strength without reinforcement is 4200 psi after 7 days and 12,225 psi after 28 days and continues to increase with age. The specific gravity of ferrocement is 2.6, FRP is1.6 and that of wood with fastenings is 0.9. Over 40 ft., when skin thickness of other materials has to be increased the ferrocement boat compares favorably with other vessels – wood, FRP and steel, because no heavy internal frames are required. Damaged area can be chipped away until surrounding area is fine. Ferrocement mix applied both in interior and exterior area is left little pruned and finally ground off. In addition, ferrocement has good heat insulation properties (Fyson, 1973).

Steel

Steel is mainly used to construct hulls of large vessels mainly beyond 50 m in length. A steel hull has a relatively thin outside shell and the minimum thickness is 2 - 3 mm. Mild steel is commonly used to construct fishing vessels where the carbon content is 0.15 to 0.30%. Steel vessels have good strength, elasticity and durability. Steel can be easily bent and twisted so that larger designs/sections can be fabricated easily with less wastage. The specific gravity of steel is 7.84 where the weight is comparatively more than wood, aluminium and FRP vessels. Steel is prone to corrosion and anticorrosive paints are essential for the hull protection. Seawater corrosion of steel can only be controlled by external factors rather than by the composition of steel since none of the common alloying elements has any commercially significant influence on corrosion. For small boat construction steel is not an efficient material.

In tropical environments where corrosion is a major problem the lower limit of the length of fishing vessels are often 15 m or more. Steel hulls may be prefabricated in section, which adds to its many advantages. The steel hull structure consists of rolled plates and profiles. Plates appear in different sizes and different thicknesses. The thinner plates (3 -6 mm) are mostly 5 - 8 m long and 1.2 - 2 m wide. Thicker plates up to 30 mm and more are up to 12 m long 2.5 m – 3 m wide. The thicknesses are mostly sub - divided by half millimeters (3, 3.5, 4, 4.5). For greater thickness over 20 mm however the difference is one millimeter.

Steel hulls are constructed either in the longitudinal type or transverse type or longitudinal to transverse type according to one of the three systems. Longitudinal construction is characterized by members stiffening the plating in the fore and aft direction. This type of construction is used in very large merchant vessels and sometimes on smaller boats. It gives a reduction in hull weight compared to other types of construction. In transverse type of construction, the main stiffening of the shell and deck plating is arranged in transverse planes at a distance of about 500 - 650 mm. The appropriate transverse elements are floors, frames and deck beams connected to each other by brackets. These types of construction are used most frequently in small and medium - sized vessels and steel fishing vessels are practically built in conformity with the transverse system. The mixed or transverse - longitudinal system is used on ships with a length of over about 100 m up to some 250 m. It combines the advantage of basic systems but due to technological reasons is not used in smaller vessels.

Environmental impacts of major boat building materials in aquatic system

Despite of its obvious advantages, all boat building materials are susceptible to the effects of marine environment, for example glass fibres are the most selected material for boat construction, which are vulnerable to the effects of sunlight in marine conditions. Glass fibre is prone to osmosis and gelcoat gets faded in sunlight resulting in the attack of UV radiation. Aluminum alloys are prone to corrosion if untreated or damaged. When new alloys are exposed, an oxide layer is formed on their surface but this oxide layer does not protect the alloy in the long term when exposed to marine environments. Periodically the paint system will need to be removed in areas of stress and the corrosion treated. Careful inspection on an annual basis of all weld seams helps in early identification of the occurrence of this problem. Aluminum reacts with some copper-based antifouling paints causing serious corrosion in environmental conditions. Therefore, antifouling containing metallic copper or cuprous oxide should never be used on aluminum, whilst copper thiocyanate based antifouling can be used if the aluminum is primed properly.

The most common form of corrosion in steel is rust. Such a reaction will take place only in the presence of water. The marine environment is therefore an ideal place for rust to occur. Due to the high flexibility and strength of steel it is hard to break, but impact damage may well result in a dent owing to the metal stretching and deforming locally. This can present problems for a protective coating, which may not be so flexible.

The fibrous nature of timber means that it has a tendency to absorb moisture from the atmosphere, and swell and contract to varying degrees depending on the type of construction. For a varnish or paint coating to stay intact it has to be quite flexible in nature. Moisture content in wood allows the growth of fungal spores, which leads to rotting and decay. Wood can also be subjected to the attack of marine borers, which eat the wood fibers. Therefore, it needs to be protected by good quality preservatives and coatings. Many different woods can be used, which can differ immensely.

Strength comparison of boat building materials

Material	Specific weight		Tensile strength	Compressive strength	Elastic modulus
	1b/ft^3	tonne/m^3	kN/m^2 × 10	kN/m^2 × 10	kN/m^2 × 10
FRP (CSM)	94	1.5	100	100	6
(WR)	106	1.7	240	170	14
Wood spruce	42	0.7	55	40	8
Ply	40	0.65	16	12	11
Aluminium	170	2.7	120	85	70
Steel	485	7.8	210	190	200

A comparative table showing the carbon consumption in the production of these materials

Material	**Net carbon emissions (kg C/metric) [1]**	**Net Carbon emissions including Carbon storage within material (kg C/ metric ton)[2]**
Framing Lumber	**33**	**-457**
Medium density fibre board	**60**	**-382**
Steel	**694**	**694**
Aluminium	**4532**	**4532**
Plastics	**2502**	**2502**

Net carbon emissions in producing 01 ton of material (OECD, 2010). Net carbon emission of wood and its relative materials (unit metric ton) were less and found to be negative where the maximum carbon emission was for aluminium followed by plastic.

While considering the environmental and economic sustainability of different boat building material, wood is an ideal material still preferred for marine boat construction. Wood is a functionally efficient material which reduce carbon footprint thereby reducing the environmental impact and simultaneously balance the cost objective. Environmental impact of any material (proposed for prolonged use) can be evaluated through Life cycle assessment procedure or LCA. The environmental impact of wood from the very first state of harvesting to the end of the product was studied and compared with other materials and found that wood as a material for boat construction contributes less pollution to the environment compared to concrete, steel, aluminium etc. (Fagerblom 2017). Høibø et al, 2015, explained that energy consumed by all the processes as embodied energy (EE) and Hsu, 2010 reported that EE of concrete, which is the highest, of 12.5MJ/kg EE, steel is 10.5 MJ/kg EE and the lowest is wood with 2.00MJ/kg EE. Studies have found that wood products have less embodied energy and are more environmental friendly as they are involved in less carbon footprint as well as air and water pollution. Furthermore, residues of wood industries are utilized in either by-product manufacturing or fuel and clean bio-energy. As forests act as carbon sink and prevent climate change and green-house gas, increasing wood use ensures sustainable development by reducing emission, increasing renewable wood use, and thus helping national economy (Fagerblom 2017).

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