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MECHANICAL PROPERTIES AND DURABILITY OF SOME SELECTED TIMBER SPECIES

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Abstract: An investigation was carried out to study physical properties, strength and durability of some timber species commercially used in Bangladesh. Seven timber species namely Teak (*Tectona grandis*), Sal (*Shorea robusta*), Sil Korai (*Albizia procera*), Rain Tree (*Samanea saman*), Jam (*Syzygium spp.*), Jackfruit (*Artocarpus heterophylus*), and Mango (*Mangifera indica*) were tested for density, specific gravity, compressive, tensile and bending strength following ASTM standards. Four different kinds of chemical environments consisting of normal water, sodium chloride (5%), sodium sulphate (10%) and hydrochloric acid (5%) were made and tested for durability in terms of strength loss over a period of 90 days. The test results revealed that Sal, Teak and Jam were the best species of using as compression member while Sal and Teak showed the best performance in tension. In static bending Sal, Sil Korai, Teak and Jam have been found suitable. With respect to durability acidic environment has been shown to be the most aggressive agent. Saline water was comparatively safer for all kinds of timber species. Overall, the Rain Tree showed excellent performance in all chemical environments having minimum loss of strength, and Sil Korai has been found to be the most vulnerable one to the same environments among all the timber species.

Keywords: *timber trees, physical properties, strength, chemical environment, durability*.

1.0 Introduction

Timber is a natural material that comes from trees. It is the oldest natural resource and the diverse ways in which it has been fashioned over the centuries tell the story of civilization better than any other material. It can last for centuries or it can perish in a second in fire. Timber has always held a significant place in the human economy. It has served man a structural material for his buildings, furnishings, tools, and weapons, and until recently as his only readily available fuel. It remains a dominant and versatile raw material especially in construction, refurbishment, furniture packaging and temporary works (Bowyer *et al*., 2003).

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Timber is one of the most environmental-friendly materials. The reason of being most popular engineering material for timber is its versatile properties like strength and durability comparing to other materials in similar approach. Strength properties are largely such properties that determine the use of timber for structural and building purposes, and innumerable other uses. Timber has several types of strength, and a timber strong in one respect may be comparatively weak in another. Again, the properties of timber vary widely not only between species but also between pieces of the same species (Lavers, 1967). In case of durability, it is the property of timber to remain in sound condition for a long time when exposed to the forces of nature in an exposed or underground condition (Aziz, 1995). Timber has varying degree of natural durability due to the variation of environment where it is exposed to (Panshin and Zeeuw, 1980). The common environments where timber generally stays for a longer period of time are air, water and soil. These media contain a huge number of chemical agents and among these some are harmful to timber and its product that deteriorate its longevity of life.

In Bangladesh timber has versatile uses and plays a vital role in national economy. There are about 500 timber tree species occurring in the forest and homesteads of Bangladesh most of which are hard woods (Sattar, 1997). Throughout the country, besides composite timbers, solid timbers are used for internal domestic works such as in making doors, windows, furniture, cabinet, panel works, etc. For agricultural implements and boat building, localized timbers are traditionally used. It is thus important to understand the basic properties and their implications in order to be able to select and to design with confidence that the desired results will be obtained. Further, since the properties of a timber dictate the uses for which it is suited, it seems to be a logical inference that timber technologist should be in a position to investigate the structure of a timber and make accurate prognostications as to its properties and proper utilization. With a view to the above essentialities, this study was aimed to investigate mechanical properties, and durability of some commercial timber species in various chemical environments.

2.0 Materials and Test Methods

2.1 Timber Species

In this study the species of timber were selected on the basis of the availability at local markets and obviously the priority was given to the species which are being used significantly at various level of its practice and got economical importance for commercial purposes. The selected species are: Teak or Shegun (*Tectona grandis*), Sal (*Shorea robusta*), Sil Korai (*Albizia procera*), Rain Tree (*Samanea saman*), Jam (*Syzygium spp.*), Jackfruit or Kanthal (*Artocarpus heterophylus*), Mango or Aam (*Mangifera indica*).

2.2 Characteristics of Selected Species

2.2.1 Teak (Tectona grandis)

Locally known as Shegun that is a medium-weight timber which is rather soft and has a very characteristic appearance. The wood is often dull yellowish when freshly cut but it turns golden brown or sometimes dark greyish-brown after exposure, often streaked greyish or blackish. It is commonly used for all sorts of house construction and structural works, high class furniture, ship building, railway sleepers, flouring veneers and decorative structural works.

2.2.2 Sal (Shorea robusta)

It is a very strong, hard, and heavy and fire protected durable timber. It is whitish in colour when freshly cut and trends to grow dark brown on exposure. The good quality timber of Sal is used for general construction purpose, especially for house building, electrical and telephone poles, boat and sleeper construction, and also for furniture and other carpentry works.

2.2.3 Sil Karoi (Albizia procera)

The wood is a moderately hard, straight-grained, strong, durable and resistant to attack by dry-wood. Its colour is light brown to light chocolate-brown. It is used for furniture, general structural works, house building, boat building, etc.

2.2.4 Rain Tree (Samanea saman)

It is a moderately strong timber having good texture of dark colour and therefore, suitable to use for furniture, cabinet making and constructional purposes. It can also produce good quality veneer for plywood.

2.2.5 Jam (Syzygium spp.)

It is a medium densed and moderately strong timber. Its shrinkage capacity is high. It is a good constructional timber due to its heavy weight and may be used for door, window and furniture. It is also suitable for boat building, cart and railway sleeper.

2.2.6 Jackfruit (Artocarpus heterophylus)

Locally known as Kanthal, which is the tree of national fruit of Bangladesh. The wood is strong, hard, durable and easy to saw, machine or carve. Its colour is yellow to light yellow. It is used for high quality furniture, house construction (doors, windows, and roof rafters), implements, boat building, cabinet making and musical instruments such as violins.

2.2.7 Mango (Mangifera indica)

It is also known as Aam and found abundantly all over the country. It is a grey and moderately strong wood. Because of its moderate weight and hardness, it can be used for rough furniture, planking, packing boxes, shoe hells, toys and making boats. If treated with preservatives it can be used for door, window and constructional purposes. It also makes good veneer for the production of plywood.

2.3 Collection of Timber

The timbers were collected from different saw mills and for each species raw samples were the freshly-cut lumber from a log of mature tree of the respective species. Primarily the samples were taken from three different locations of freshly sawn lumbers for each category of the tests. The raw samples were stored in a dry place having a sufficient aeration system. Then the air-dried raw samples were cut into the desired size and shapes following the standard specifications for each of the properties to be tested.

2.4 Testing of Physical and Strength Properties

2.4.1 Density and Specific Gravity

Among the physical properties density and specific gravity are more important as they are closely related to the strength properties of timber (Winandy, 1994). Density is not a constant property for timber as it varies remarkably with the amount of moisture content. So, a number of density figures can be obtained at different stages of its moisture content from top to bottom of a tree. Basically density is measured for three identical conditions of timber like green (with the same moisture content as in the living tree), air-dry (at equilibrium with ambient condition and oven-dry (after heating in an oven at 103 ºC until constant mass is achieved) conditions. In this study, only the air dry density has been determined.

The specimens for density measurement were 50 x 50 x 150 mm solid wood blocks and completely free from knots, checks, flaws and any other defects. The volume of the specimens was calculated measuring the dimensions of length, width and thickness with the help of a vernier scale. The density was obtained by determining the air-dry mass per unit volume for each of the test specimens.

The specimens for specific gravity were prepared from the same blocks used for density determination. A representative segment of full cross-sectional dimension 50 x 50 mm and 25 mm in length (parallel to grain) was carefully cut from each of the density specimens to ensure clean-cut surfaces. All loose fibers had been carefully removed before the specimens were weighed and measured. The specimens were made regular in shape with right-angle corners for determination of volume by linear measurement, and were completely free from knots and other defects. The specific gravity was determined according to ASTM D 2395-93 standard.

2.4.2 Compressive Strength

Two types of laboratory tests were carried out for the determination of compressive strength of timber: compression parallel to grain and compression perpendicular to grain. The basic difference between these two types of compression is only in the direction of loading with respect to the direction of grain. Both the tests for compression were made on the specimens having dimension of (50 x 50 x 200 mm) according to ASTM D 143-94 standard. Special care was taken to ensure the end grain surfaces parallel to each other and at right angles to the longitudinal axis. Using universal testing machine the load was applied continuously at a rate of 0.6mm/min. throughout the test until complete failure occurred.

Immediately after the test a section of approximately 25mm in length with full cross-sectional area (50 x 50 mm) was cut off from the test specimen to determine its moisture content during the test.

2.5 Tests for Durability

In this study, the durability of timber has been evaluated on the basis of the resistance to various aggressive and non-aggressive chemical solutions. The resistance to chemical attack was measured determining the loss of compressive strength after 90 days of immersion to respective chemical solutions.

2.5.1 Selection of Chemical Environment

To create different environment in the laboratory, four different solutions were made including natural water. The chemical solutions are: sodium chloride (5%) solution, sodium sulphate (10%) solution, and hydrochloric acid (5%) solution.

Natural Water: It is a vast environment occupying 75% of the earth surface. Quantitatively it may differ from place to place but not significantly differing in its chemical composition. In contact with timber, water acts as a solvent only and there is no effect of minor chemicals present in water.

Sea water: To make an artificial marine environment, sodium chloride (NaCl) was mixed with fresh water at a specific rate. It is known that the sodium chloride content in sea water is about 3.5%. In this study, the concentration of the solution was increased up to 5% just to accelerate the action within short stipulated time of study.

Sulphate solution: Sulphates are salts of sulphur element that contain a charged group of sulphur and oxygen atoms. The sulfate is widely distributed in nature both as free and combined forms (Parkes, 1963). It is comprehensible that this component is prevailing dominantly over all environments like soil, air and water and has become a foremost concern to the specialists for the sake of environment and its products. In this study, sodium sulphate (Na_2SO_4) was taken into consideration as it is an active source of sulphate ion where sodium presents as a neutral inorganic compound. The sodium sulphate solution was prepared by mixing anhydrous sodium sulphate salt in water at a concentration of 10% (w/v).

Acid solution: It is generally known that in contact with wood, acids cause hydrolysis of the polysaccharides which are the basic constituent of timber. Among all the industrial acids hydrochloric acid is mostly used. In this study, 5% hydrochloric acid (HCl) solution was prepared to create an acidic environment for timber. All the solutions were made separately in a plastic container having the capacity of 30 litres. In case of salt and sulphate solutions water has been used as a solvent whereas in acid solution water was added as diluting agent.

2.5.2 Immersion of specimens in solutions

Three specimens for each of the selected timber species were taken for a particular chemical environment. The dimension of each specimen was 50 x 50 x 200 mm. Seven timber species with three observations of each i.e. a total of twenty one specimens were tested for each environment. Before immersion into solution, the specimens were weighed with the help of an electrical balance. Plastic containers having different chemical solutions and the arrangement of timber specimens in a container are shown in Figure 1. The specimens in the solution were altered (upside down and vice versa) periodically. The weight of each specimen was recorded with an interval of ten days after immersion. After ninety days of immersion all the specimens were taken out of the solutions and left in a dry place for twenty four hours to attain surface dry condition. Then each specimen was tested for its ultimate compressive strength using Universal testing machine. The strength values after ninety days of immersion were compared with the usual strength at air-dry condition. The percentage reduction of strength after immersion was calculated for each of the timber species for a particular environment.

Four different containers

Timber in solution

Figure 1: General view of containers with arrangement of timber in chemical solutions

3.0 Results and Discussion

3.1 Physical properties

Table 1 summarises the density and specific gravity of seven selected timber species where Sal and Jam show the higher values of specific gravity as well as the density. Sil Korai has a moderate specific gravity of 0.65 whereas Teak (0.54), Rain tree (0.53) and Aam (0.55) have almost the same value with a small deviation. Kanthal was found to have the lowest value in both cases of density and specific gravity among the selected species. Almost similar findings have been reported by Sattar (1997) where the grading of species on specific gravity were found to be 0.72, 0.69, 0.59, 0.57, 0.54, 0.48 for Jam, Sil Korai, Teak, Rain Tree, Aam and Kanthal, respectively. It is known that the specific gravity of timber depends on the arrangement of the individual cells or more specifically the amount of cell cavities and intercellular spaces that occupy most part of a particular volume of timber. So, the specific gravity can vary between samples within the same species.

Table 1: Density and Specific gravity of the timber species

Timber species	Density (kg/m^3)	Specific gravity
Teak	665	0.54
Sil Korai	696	0.65
Sal	921	0.84
Rain Tree	642	0.53
Kanthal	615	0.51
Jam	817	0.70
Aam	596	0.55

3.2 Strength properties

The test results on compressive strength of the selected timber species are presented in Figure 2. It shows that the highest compressive strength was recorded for Sal (47.65 MPa) whereas Rain tree showed the minimum strength of 23.25 MPa. The strength of Teak has been found to be almost same of Sal species and somewhat greater than the strength of Sil Korai. The compressive strength of Kanthal (37.90 MPa) was considerably higher than Jam, Aam and Rain Tree. In a recent study, a close value of the maximum crushing strength of Teak was reported as 50MPa in compression parallel to the grain (Isabel *et al*., 2011). Similar pattern of compressive strength was observed in the research findings of Sattar (1997) and Sarker *et al*., (1995). It has also been observed that Teak exhibited the best performance in compression (perpendicular to grain), which is about 70% of that in parallel to the grain. Figure 2 further shows that among the seven species Aam (8.60 MPa) is very weak in compression perpendicular to its grain and only 30% of the strength parallel to the grain.

From Table 1 & Figure 2, a close relationship can be seen between density and strength figures i.e. the high density timber offers the highest strength. But, it may not be ideal for all cases because the density figure is always controlled by the moisture content condition of timber of a particular volume. It can also be seen that Jam species shows lower strength despite its high density.

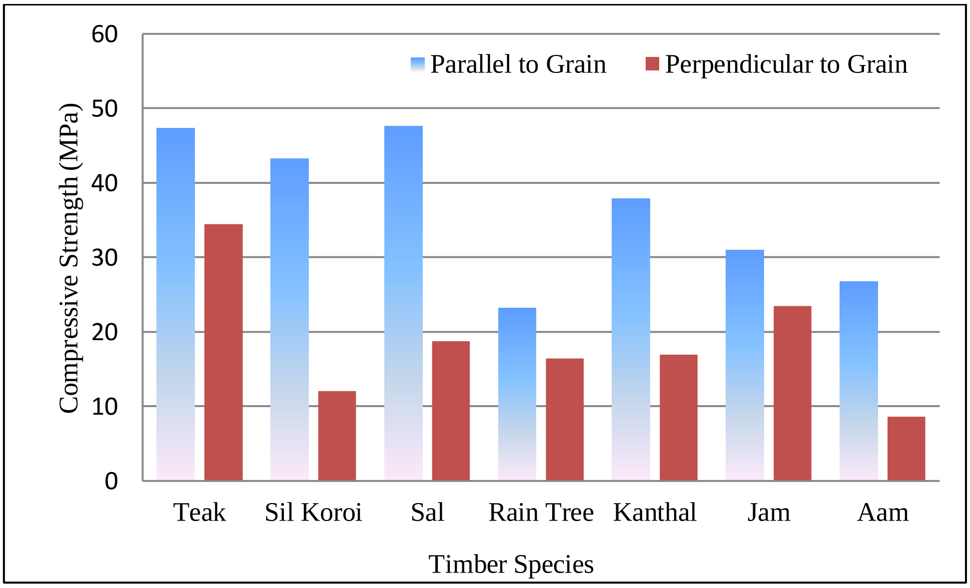


Figure 2: Compressive strength of different timber species.

According to Desch and Dinwoodie (1996) it could happen due to the chemical composition of cell wall materials. Strong carbon bonds in the fibres aligned along the axes of the cells, which are parallel to the grain, give the high strength and modulus of elasticity in this direction. Across the grain, the cells are hollow and are held together by weak, low molecular weight resins leading to low strength.

3.3 Durability

The durability performance of various timber species was evaluated by comparing the percentage loss of strength after an exposure period of 90 days in a particular environment. The absorption behaviour of each timber species was also monitored by recording the weight of each test specimen taken at an interval of ten days after immersion.

3.3.1 Action of water

It is known that normal water only dissolves the extractive components of the wood substances. So, no chemical reaction is taken place between timber cell-wall components and neutral solvent like water. The results of durability test in water, presented in Table 2, show that after ninety days of immersion Sil Korai lost about 44% of its breaking strength whereas Sal species shows the minimum (9%) loss of strength.

The loss of strength for Jam and kanthal were found much closer to Sal and Sil Korai species respectively. Table 2 also reveals
that minimum percentage of loss was found for the timbers of high relative density like Sal and Jam species.

It is important to note that Aam species is much vulnerable to this media. After first ten days of immersion, the average weight of Aam species was increased to about 82% of its air-dry weight (Figure 3). At the same time the rate of water absorption was found to be the lowest (10%) for high density timber like Sal species. For other species like Teak, Sil Korai, Rain Tree, Kanthal and Jam, the rate was found in the range of about 18 to 28% in first 10 days of immersion. Fig. 3 further shows that after 60 days of immersion all species attained almost saturation condition and overall the average rate of absorption for all species was found to be roughly 42% of its air-dry weight in water except the wide variation for Aam species (90%).

Table 2: Percentage loss of strength after immersion in normal water

Timber species	Compressive strength, MPa		Loss of strength (%)
	Air-dry condition	After immersion	
Teak	47	34	28
Sil Korai	43	24	44
Sal	48	44	9
Rain Tree	23	20	14
Kanthal	38	23	40
Jam	31	27	11
Aam	27	20	25

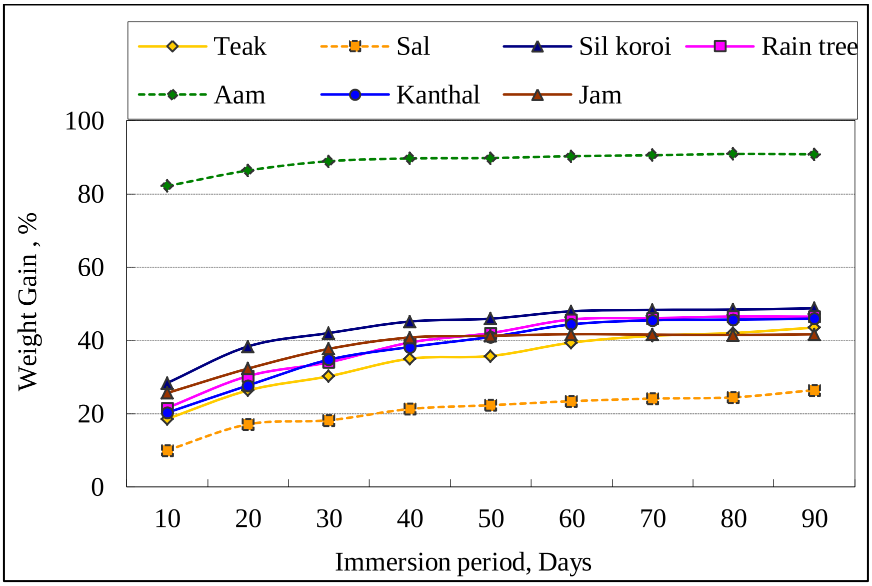


Figure 3: Rate of weight gain during immersion in water.

3.3.2 Action of salt

For the test of durability of timber in marine environment, aqueous solution of sodium chloride (5%) was made in the laboratory. After 90 days of immersion, the average strength of each selected species was recorded. Table 3 depicts that Sal and Rain Tree showed the highest resistance to saline water having the loss of strength of only 2% and 3% respectively. Sil Korai loost 32% of its strength and this is the highest among the selected species. Table 3 further shows that Teak and Jam species were found in the same category that lost 16% strength whereas Aam and Kanthal species experienced comparatively lower value of 12% and 10% respectively. From Table 2 and 3, it is understood that aqueous solution of salt is more favourable for timber than normal water except Jam species that showed better performance in water than the salt environment. The reason for this discrepancy can be found from Figure 4, where, the percentage of weight gain i.e. the amount of absorption of Jam timber after 90 days of immersion in saline water was found to be higher (53%) than that (42%) in normal water. Similar to water, the rate of absorption of Aam species was higher than other species in sodium chloride solution. But the total amount of absorption i.e. percentage of weight gain (82%) was less than that in water (91%) and it was found true for all species except Jam. A similar observation has been made by Panshin and Zeeuw (1980) who found that the timber treated with low concentrations of water-soluble salts as protection against biological attacks exhibits little decrease in strength properties under normal condition of service.

Table 3: Percentage loss of strength after immersion in sodium chloride solution

Timber species	Compressive strength, MPa		Loss of strength (%)
	Air-dry condition	After immersion	
Teak	47	40	16
Sil Korai	43	30	32
Sal	48	47	2
Rain Tree	23	23	3
Kanthal	38	34	10
Jam	31	26	16
Aam	27	23	12

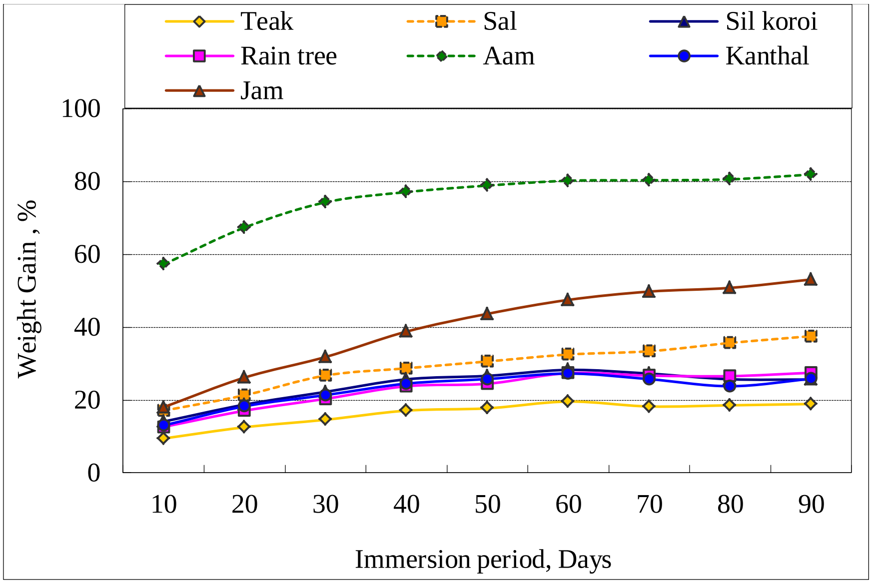


Figure 4: Rate of weight gain during immersion in sodium chloride solution.

3.3.3 Action of sulphate

Table 4 presents the loss of strength of the selected timber species after 90 days of immersion in 10% sodium sulphate solution. It can be seen that among seven species, Jam exhibited the highest resistance to sulphate environment with minimum loss of only 7%. Rain Tree was found better than Teak and Kanthal species whereas Sal was found to be the worst one. Like water and salt environment Sil Korai shows the lowest retention of wet breaking strength in sulphate environment. In Figure 5 it is seen that the rate of absorption of Aam in sulphate solution was higher than other species. But, the final weight gain of each species was found less comparing to water and salt environment.

Table 4: Percentage loss of strength after immersion in sodium sulphate solution

Timber species	Compressive strength, MPa		Loss of strength (%)
	Air-dry condition	After immersion	
Teak	47	36	25
Sil Korai	43	31	28
Sal	48	37	23
Rain Tree	23	21	10
Kanthal	38	29	22
Jam	31	29	7
Aam	27	23	13

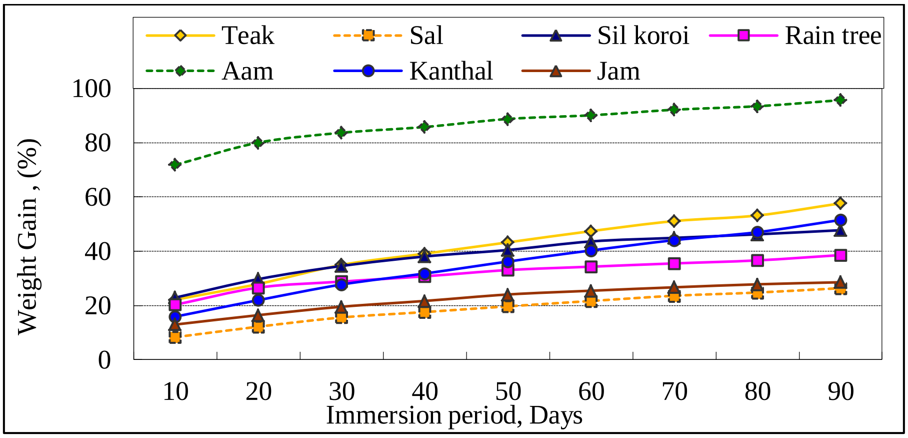


Figure 5: Rate of weight gain during immersion in sodium sulphate solution.

3.3.4 Action of acid

The test results of durability in hydrochloric acid solution, summarized in Table 5, reveals that the percentage loss of strength for all the species varied from 52% to 62% of its air-dry strength. Kanthal and Rain Tree showed comparatively minimum values of 52% and 53% respectively; whereas the maximum loss of strength was seen for Jam species. Wangaard (1966) observed minor change in strength of some hardwood species after they had been soaked in 2% hydrochloric acid for 32 days. Using more drastic treatment, by soaking in 10 % hydrochloric acid for 4 days at 50°C, he also observed that the strength reduction goes up to 70 percent in bending condition.

Table 5: Percentage loss of strength after immersion in hydrochloric acid solution

Timber species	Compressive strength, MPa		Loss of strength (%)
	Air-dry condition	After immersion	
Teak	47	20	57
Sil Korai	43	18	58
Sal	48	21	57
Rain Tree	23	11	53
Kanthal	38	18	52
Jam	31	12	62
Aam	27	11	60

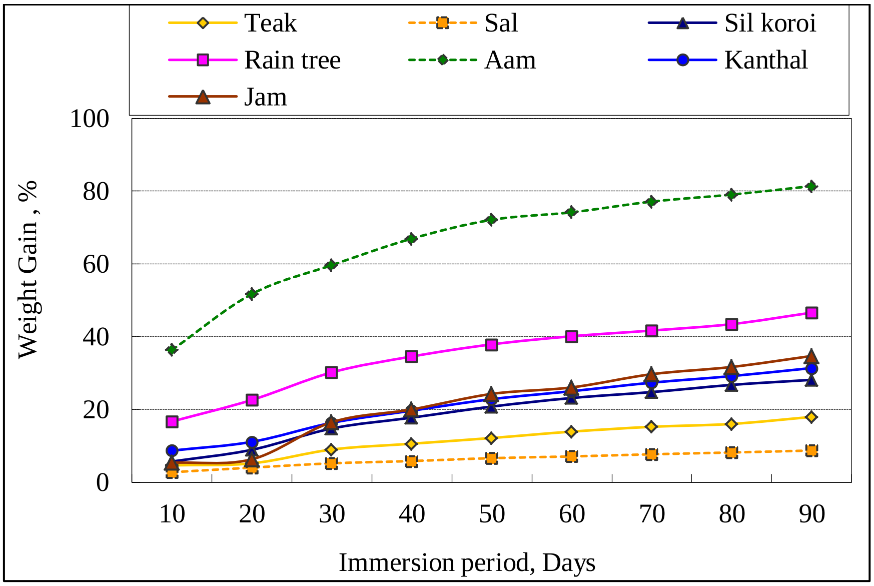


Figure 6: Rate of weight gain during immersion in hydrochloric acid solution.

The resistance of timber against acid attack varies depending upon the type of timber and the nature of acidic media. Usually acid causes hydrolysis of polysaccharides, the major constituent of timber substances. In acids, the hydrolysis of hemicelluloses occurs more rapidly whereas the cellulose is attacked slowly. According to Panshin and Zeeuw (1980), resistance to attack is influenced by the degree of crystallinity of the cellulose, while low pentose contents, for example, in conifers increases the resistance to both acid and alkalis.

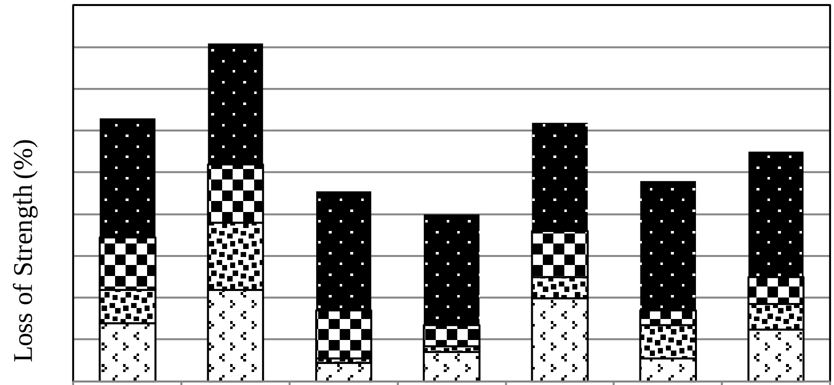
Like water, salt and sulphate environment the rate of absorption in acid solution was also found to be the highest for Aam species (Figure 6). Comparing to the past three environments, it is also observed that the percentage of weight gain for most of the selected species after immersion is greater in hydrochloric acid solution. It can also be observed that the percentage of weight gain of the high density timber like Sal was found to be the minimum in all solution except for in sodium chloride solution.

It is interesting to note that there has been no significant relationship between loss of strength and the rate of absorption as well as percentage of weight gain among the selected species. Table 6 summarizes a combined figure of the percentage retention of strength of each species after immersion in the selected chemical environments. It has been observed that all the species have shown more or less similar strength behaviour in hydrochloric acid solution. The maximum variation in the loss of strength among the selected species was found to be 35% in water whereas 30% and 21% loss was recorded for salt and sulphate environment respectively. In acid solution the deviation of strength loss within the selected species has been found to be a minimum of 10% only. It can also be seen that the average retention of strength was maximum in salt and minimum in acid solution which is about 87% and 43% respectively. Moreover, sulphate environment is observed to be less aggressive than water environment since the average retention of strength was found to be 82% and 76% for sulphate and water environment respectively.

Table 6: Percentage retention of compressive strength of timber species at various chemical environments

Solutions	**Retention of compressive strength (%)**						
	Teak	**Sil Korai**	**Sal**	**Rain Tree**	**Kanthal**	**Jam**	**Aam**
Water	72	56	91	86	60	89	75
Salt	84	68	98	97	90	84	88
Sulphate	75	72	77	90	78	93	87
Acid	43	42	43	47	48	38	40

It can be summarised from Figure 7 that the Rain tree species has shown the best resistance to all the chemical agents and Sil Korai has been found as the most vulnerable species to the same environments as compared to other species. Overall, the saline water and sulphate atmosphere have been found comparatively safe or less attacking to timber than water and acid environment.



	Teak	Sil Koroi	Sal	Rain Tree	Kanthal	Jam	Aam
Acid	57	58	57	53	52	62	60
Sulphate	25	28	23	10	22	7	13
Salt	16	32	2	3	10	16	12
Water	28	44	9	14	40	11	25

Figure 7: Percentage loss of strength of timber at various chemical environments.

4.0 Conclusions

It requires no special knowledge to appreciate that the strength and durability of any building material have an important bearing on suitability for a particular purpose. In regard to timber, laboratory tests on small clear specimen are of considerable practical importance for comparative study as they provide an indication of the performance behaviour of individual species. Along with strength, experimental investigations on durability of some common timber species of Bangladesh in different chemical environments have been carried out in the present study. Based on test results, this study can be concluded with the following remarks:

1) Among the seven selected species, Sal and Jam species have been found to be high density timbers. Teak, Sil Korai and Kanthal are moderately densed, whereas Aam and Rain Tree are found relatively with low density.
2) In compression, parallel to the grain, Sal and Teak are the best timber species. On the other hand, Aam and Rain Tree species are found with lower compressive strength values.

3) There exists a good correlation between the specific gravity and strength properties of timber. The strength of timber has been found to be directly proportional to its specific gravity.
4) Regarding durability, acid has been found to be the most aggressive agent causing significant damage to the strength of timbers. Overall, Rain Tree species has executed better performance in all chemical environments having minimum loss of strength, and Sil Korai has been found as the most vulnerable one to the same environments among the selected timber species.
5) Results obtained and the observations made in this study suggest that for a particular work and in a particular environment timber should be used appropriately according to their properties in order to obtain fuller benefits and better services.

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