Wood Preservation: Improvement of Mechanical Properties by Vacuum Pressure Process

Md. Fazle Rabbi, Md. Mahmudul Islam, A.N.M. Mizanur Rahman

Abstract— **Wood, being a biological product, is liable to deterioration unless it is properly protected. The main reasons of deterioration of timber in service are decay due to fungal infection, attack by insects (borers and white ants), marine organisms and fire. Protection of wood is carried out from these agents by using preservative which can properly be used by proper design of preservation plant. Proper design of such plant is very essential to increase the lifespan of wood economically. Among the various wood preservation techniques, pressure processes are the most permanent technique around the world today. In the Full cell process, wood is allowed to absorb as much liquid chemicals as possible during the pressure period, thus leaving the maximum concentration of preservatives in the treated area. Usually, water solutions of preservative salts are employed with this process but it is also possible to impregnate wood with oil. The desired retention is achieved by changing the strength of the solution.**

A Full cell pressure wood preservation system was designed and constructed in Mechanical Engineering Department of KUET and its performance was tested. The pressure cylinder was constructed using locally available materials and different physical properties of wood were measured. It was observed that the weight of wood reduces due to loss of moisture, density, retention, penetration of preservatives into wood due to pressure in the cylinder. The penetration is more or less uniform throughout the surfaces.

Index Terms— **Deterioration, Full cell process, Physical properties of wood, Wood preservation.**

I. INTRODUCTION

Wood is one of the earth's most valuable and abundant renewable natural resources. It is a gift of nature and is the only working material that is self- generating. It is a material used by men from thousands of years without precise knowledge of its properties. Wood has been the most useful of all the readily available materials to mankind. To create an equilibrium status of forest products of a country, an equal operational practice between three correlated producers of plantation, harvesting and preservation of wood is essential. In this case, wood preservation can play an important role in bio-conservation and protection of environment.

The main enemies of wood which damage it are fungus, termites, beetles, carpenter ants and marine borers. Besides this temperature, rain and the ultra violet ray can damage the timber. The amount of damage by the second is negligible in comparison to the first enemies. By applying proper preservation technique, it is possible to protect the timber from these enemies. Preservation is the only appropriate way to make the timber toxic and protect it [1].

The primary importance of the preservation treatment of wood is to increase the life of the material in service, thus decreasing the ultimate cost of the product and avoiding the need for frequent replacements [2]. The extension of the service life of timber by the application of appropriate preservatives has another significant effect in the field of wood utilization. In addition, preservation contributes to the reduction of the demand for replacement of wood, thus conserving the forests. With suitable chemical treatment, the life of timber can be increased to 5-10 times its normal life and its fire resistive property to 2-3 times the normal [2]. Wood can also be chemically treated to protect it from fungi causing blue stain, brown rot etc. which lower the market value of the timber. Wood has its fuel value and teak value. Wood's fuel value can't change by preserving but its teak value can change by increasing the life of wood. Thus, wood preservation helps in the proper utilization of wood and in the conservation of wood resources and forests [3].

Wood preservation is the art of preserving timber against the agencies of deterioration. In practical sense it refers to improve the natural durability of wood by treatment of wood preservatives which are toxic to fungi and insects and also other wood decay agencies to increase the service life. Preservative treatment of timber therefore forms a very important part of the national effort to conserve the material resources of the country. The preservative treatment depends on the wood species, moisture content and its anatomical structure. The widely used preservation method in the Bangladesh, as well as in the world, is Full cell pressure process. Besides this, soaking or dipping method is used for different wood species because it is very simple and anyone can treat wood by this method. Wood, bamboo and sun grass are usually treated with Chromate- Copper-Arsenate (CCA) but after some laboratory trials at Forest Research Institute (FRI), Chromate-Copper- Arsenate (CCA) is being replaced by Chromate-Copper- Boric acid (CCB) due to low cost and available in market [4]. Chromate-Copper-Boric acid (CCB) is not only low cost material but also environment friendly.

Due to environmental concerns regarding the use of certain classes of preservatives, there has recently been a renewed interest in wood preservation. Wood preservation represents a process that is used to improve the material properties of wood, but produces a material that would be disposed of at the end of a product life cycle without presenting any environmental hazard. Although wood preservation has been

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the subject of a great deal of study at an academic level for over 50 years, it is only comparatively recently that there has been significant commercial development.

A laboratory scale Full cell pressure wood preservation system has been developed in the laboratory of KUET for preserving wood. The locally available materials are used in the system. The system has two components e.g., the drying or seasoning chamber and the pressure cylinder with necessary arrangements. Its performance of the system was tested using mango wood using CCB chemicals and the products were tested by using chemicals. The results are very impressive to go forward for a real system.

II. Wood Preservation Technology in Bangladesh

Bangladesh is not a big country in respect to land area. The total land area of Bangladesh is 14.3 million hectares of which 2.2 million hectares (15%) is under forest cover and only 0.93 hectares (6.5%) are under tree cover. That is why there is a huge deficit of timber (44%) and fuel wood (53%) in Bangladesh. So, in Bangladesh prospective wood preservation can play a vital role in bio-conservation and protection of environment. Biotechnology has brought about a revolution in the way the plant genetic resource can be utilized. Scientists have treated many timber species with Chromate-Copper-Arsenate (CCA). Because of the environmental effect of arsenic compound like Arsenate, the use of CCA as preservative is now a debating issue. So, due to low cost and available in local market, Chromate-Copper-Boric acid (CCB) is now being used as wood preservative. Moreover, lacking arsenic compound, CCB seems to be environment friendly and widely accepted.

Bangladesh Forest Research Institute (BFRI) has developed noteworthy technologies and generated useful information regarding forest management and utilization of forest resources. Notable among them are: simple technique for propagation of bamboo; technique for the enhancement of service life of rural housing materials; propagation of forest tree species and tissue culture of bamboo; seasoning of timber using solar energy: a simple, inexpensive and effective solar kiln has been developed for seasoning timber using solar radiation; non-conventional timber for railway sleepers; the major insect pest and diseases in nurseries and plantations have been identified and also control measures have been suggested. These measures can be applied in nursery management; utilization of wood waste; technique has been developed for the utilization of wood waste for making novelty items, panel products and particleboard. This will not only save resources from wastes, but also keep the environment clean.

III. Different Wood Preservation Processes

Wood preservation processes may be of non-pressure processes and pressure processes. Non-pressure processes involve the application of the preservative by means of brushing or spraying, dipping, soaking, steeping or by means of hot and cold bath. There is also a variety of additional methods involving charring, applying preservatives in bored holes, diffusion processes and sap displacement.

On the other hand pressure processes are the most permanent method around today in preserving timber life. Pressure processes are those in which the treatment is carried out in closed chambers with applied pressure and/or vacuum. These processes have a number of advantages over the non-pressure methods. In most cases, a deeper and more uniform penetration and a higher absorption of preservative is achieved. Another advantage is that the treating conditions can be controlled so that retention and penetration can be varied. Thus, pressure processes can be adapted to large-scale production. The high initial costs for the equipment and the energy costs are the biggest disadvantages of pressure process. Different types of pressure processes are Full cell process, Fluctuation pressure process, Boucherie process, High pressure sap displacement system.

In the Full cell process, the intention is to keep as much of the liquid absorbed into the wood during the pressure period as possible, thus leaving the maximum concentration of preservatives in the treated area. Usually, water solutions of preservative salts are employed with this process but it is also possible to impregnate wood with oil. The desired retention is achieved by changing the strength of the solution. William Burnett patented this development of Full cell Impregnation with water solutions in 1838.

Before wood is used for most construction purposes and especially before it can be pressure-treated, its moisture content has to be reduced from its freshly felled or ‘green’ condition to a much lower level, commonly 15% to 25%. This moisture content is reduced by seasoning. Seasoning of timber is a process of drying wood to the moisture content it will attain in use or in other words to a suitable moisture content warranting equilibrium with the prevailing atmospheric condition in service. As soon as a tree is cut down, it begins seasoning or drying, and water in the wood starts to evaporate. Different types of seasoning are kiln seasoning, heated room drying, steam drying, steam vacuum process, water seasoning, solvent seasoning, spray drying process, dehumidifier drying etc.

IV. Construction of Full Cell Pressure System

The Full cell pressure system consists of two major parts. These are the pressure cylinder and the seasoning or drying chamber. The pressure chamber must sustain the pressure of the preservatives during its retention.

A. Pressure Cylinder

A 350 mm diameter, 600 mm long and 3.25 mm wall-thickness treating chamber was constructed from MS sheet to sustain about 7 bar pressure. Three tapings were made in the chamber to provide the air in, preservative in and the other for creating vacuum in the cylinder. A pressure gauge is also fixed to notice the instantaneous pressure inside. The Photographic view of the Full cell pressure system is shown in Fig. 1.

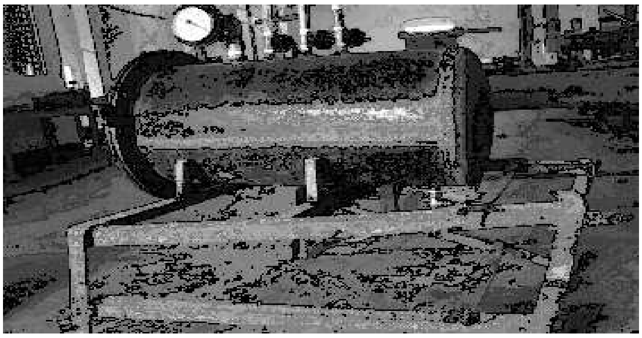

Fig. 1 Photographic view of Pressure Cylinder

B. Seasoning or Drying Chamber

The wood specimen must be dried before chemical treatment. Thus, a drying chamber is necessary for this purpose. A cabinet type solar dryer was constructed and used as a solar kiln to fulfill the seasoning purpose. For the preservation of wood, first, the moisture of the wood specimen should be reduced to a minimum level which should not exceed 25% in the wood specimen. This criterion serves the good penetration of preservatives in wood. The schematic of the drying chamber constructed for the same is shown in Fig. 2. In the seasoning chamber air is heated in the collector part and become wormer and lighter. This hot air enters to the drying chamber naturally and come in contact with the wood specimen. Thus, the moisture removes from the wood and gets dried.

V. Methodology of Pressure Process

A process of preservative treatment of wood is that, which uses a pressure vessel and first draws a vacuum on the charge of wood and then introduces the preservative without breaking the vacuum. This process is also known as Bethell process.

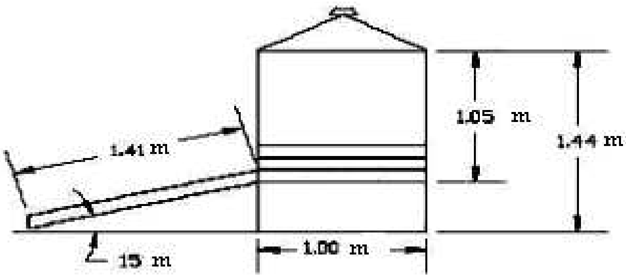

Fig. 2 Schematic diagram of Seasoning Chamber

After drying the wood specimen is placed inside the pressure chamber. A vacuum creating device (vacuum pump) or an air compressor with reverse flow of air is connected with the treating chamber to create an initial vacuum of about 550 mm of Hg inside the closed chamber. Then preservatives are introduced into the chamber without releasing the vacuum and the chamber is filled with preservatives so that the wood specimen is fully dipped into this preservative solution and then pressure is applied by introducing air into the cylinder by a compressor for treatment of the wood efficiently.

The sequence of procedures used in the Full cell process is shown in Fig. 3.

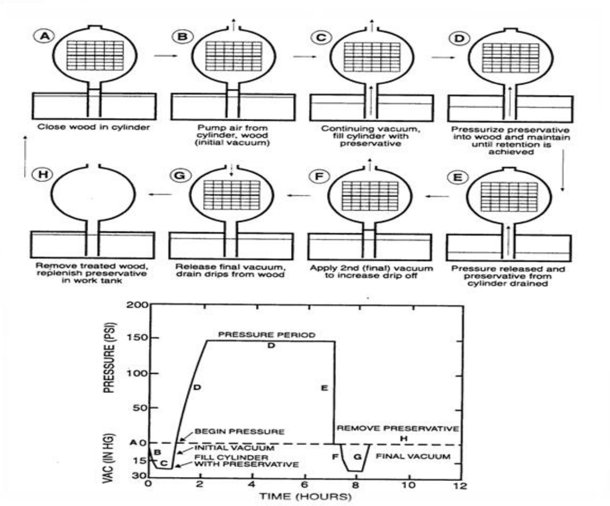

Fig. 3: Treating sequences and pressure change in the Full cell process

A. Dried wood is enclosed in a pressure cylinder or retort.
B. Vacuum pump to remove most of the air from the cylinder is used. A partial vacuum of about 550 mmHg hold to allow air to be removed from the wood.
C. Without releasing the vacuum, the cylinder is allowed to fill with preservative.
D. 4 bar pressure is applied to the preservative by an air compressor to force into the wood cell previously occupied by air, now occupied by a partial vacuum.
E. When the desired and measured amount of liquid preservative has been absorbed, applied pressure is released and drained the cylinder.
F. A "final" vacuum 550 mmHg is applied to expand the air remaining in the wood. This forced excess liquid to exude from the surfaces and run off.
G. Finally vacuum is released. As the remaining air in the cells contacts, much of the surface wetness reabsorbed into the wood.

At last the treated wood products were released from the cylinder. After that, the samples were dried for the determination of penetration and retention.

The components of preservative chemicals are Potassium dichromate ($K_2Cr_2O_7$), Copper sulfate ($CuSO_4$) and Boric Acid (H_3BO_3) which are available in the local market. The acidity of the solution (P^H value) is determined and for first treatment the value of P^H obtained is found 4.00 and for second treatment, it is found 4.30. In preparation of 1 kg of CCB chemicals, the weight of Potassium dichromate is 0.40 kg, Copper sulfate is 0.40 kg and Boric Acid is 0.20 kg. This 1 kg CCB chemical is mixed with 20 liters of water for making 5% solutions. In order to reduce cost and chemicals, for the second and successive charges, 1 kg of CCB is prepared with 20 liters of water and is mixed with 18 liters of CCB chemicals solution which remain after first treatment and a total of 38 liters of CCB solution is prepared and charged to the cylinder. Before charging, the wood specimens are sized to required dimension and are arranged in different stages.

The penetration of preservatives into the timber can easily be determined on site by using color reagents. For observing boron penetration, at first exactly 10 gm turmeric with 90 gm ethyl alcohol is taken and is filtered to obtain clear solution. Secondly, 20 ml of concentrated hydrochloric acid is diluted to 100 ml with ethyl alcohol and then it is saturated with salicylic acid. Generally, 13 gm of salicylic acid is required per 100 ml solution. The sample for penetration assay is dried prior to make the final cut to expose the surface for spraying. A smooth surface shows the results of the spot test better than a rough surface. The surface must be dried otherwise the test will not be satisfactory. First, solution is applied, preferably by spraying, or with a dropper, on the surface to be treated. The surface being treated is then allowed a few minutes to dry. Solution 2 is then applied in a similar manner to the areas that had been colored yellow by the application of solution 1. The color changes are observed carefully and had shown up a few minutes after application of the second solution. In the presence of boron, the yellow color of the turmeric solution is found turned red.

For measuring Copper penetration, exactly 0.5 gm Chrome Azurol S concentrated and 5 gm sodium acetate is dissolved in 80 ml of water and dilute to 500 ml. The solution is sprayed over freshly cut surfaces of treated wood sample. Deep blue color reveals the presence of copper and dried wood gave better results.

Preservative retention of wood samples is calculated by volumetric analysis. To determine the retention, two weights of every sample were taken i.e., oven dry weight before treatment and oven dry weight after treatment. Then the weight of preservative solution penetrated in the sample, is calculated from the difference of that two weights. Retention is expressed as lb/cu ft. In fact retention is the ratio of the weight of salt (preservatives) to the volume of sample.

VI. Results and Discussions

The various parameters measured during the drying of 6 (six) wood specimens are shown in Table 1. The table shows the weights of each specimen after every day. The variation of water reduction with respect to time in the wood specimen is shown in Fig. 2. Weight test of wood specimen shows that it is reduced as it is dried at the solar kiln. At cabinet type solar drier, the temperature is fluctuated with solar intensity. As a result, the loss of weight is not uniform which is evident from Fig. 2. Initially the weight of wood reduces rapidly but after some days, the reduction in weight is comparatively low and finally weight is constant.

Table 1 Weight change of wood specimen during drying

Time (day)	S-1 (gm)	S-2 (gm)	S-3 (gm)	S-4 (gm)	S-5 (gm)	S-6 (gm)
1	690	730	700	735	625	700
2	665	700	685	720	600	660
3	625	670	640	670	570	605
4	620	665	635	660	560	600
5	605	645	630	655	545	590
6	590	620	610	650	530	550
7	550	590	580	610	500	540
8	520	550	540	580	460	520
9	400	415	440	450	360	430
10	390	410	430	450	360	430
11	390	405	420	450	360	430

The densities of wood specimens before and after treatment are shown in Table 2 and also in Fig. 3. It is evident from both the Table and Figure that the densities of wood specimens are increased in all cases.

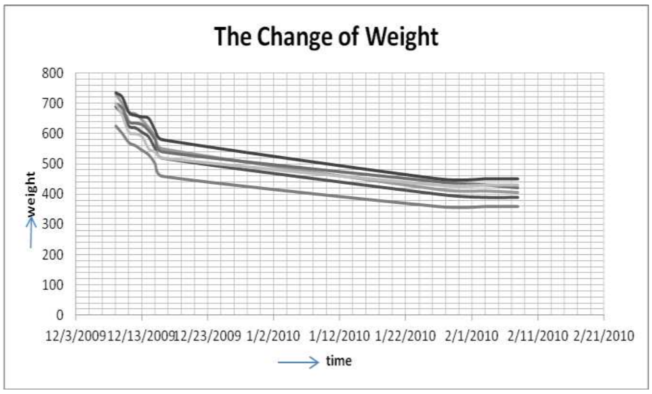

Fig. 4 Weight-change of test specimen with time

Table 2 Change of density of specimens and Retention

Sampl e No	Before Treatment , Density in kg/m^3	After Treatment, Density in kg/m^3	Retention in kg/cubic meter
1	496.183	636.132	139.949
2	521.628	699.745	178.117
3	547.074	737.913	190.839
4	572.519	636.132	63.613
5	458.0153	508.906	50.891
6	547.0738	636.132	89.058

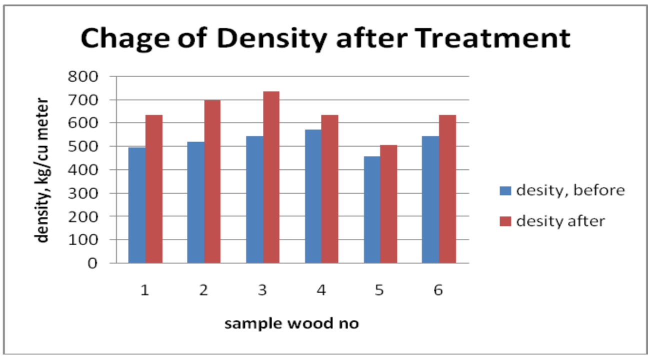

Fig. 5 Change of density before and after treatment

The change of densities was also not uniform. The comparative change of densities before and after treatment is illustrated in Fig. 3, which indicates the increase of density as it absorbed preservative solution. More retention ensures good preservative treatment and long life of test samples.

The percentage reduction of moisture contents is shown in Table 3. Initially, moisture content was so high. After drying, the moisture content is reduced. The reduction of moisture which illustrates in Fig. 4 is found from 3.76% to 76.92% for sample-1, from 4.29% to 78.05% for sample-2, from 2.19% to 62.79% for sample-3, and so on. For good treatment and effective penetration of preservative it is required to maintain moisture content within 30%. This graph shows the increase of reduction of moisture content day by day

Table 3 Percentage reduction of moisture content

Time (day)	S-1 %	S-2 %	S-3 %	S-4 %	S-5 %	S-6 %
1	3.76	4.29	2.19	2.08	4.17	6.06
2	10.40	8.96	9.38	9.70	9.65	15.70
3	11.29	9.77	10.24	11.36	11.61	16.67
4	14.05	13.18	11.11	12.21	14.68	18.64
5	16.95	17.74	14.75	13.08	17.92	27.27
6	25.45	23.73	20.69	20.49	25.00	29.63
7	32.69	32.73	29.63	26.72	35.87	34.62
8	72.50	75.90	59.09	63.33	73.61	62.79
9	76.92	78.05	62.79	63.33	73.61	62.79
10	76.92	78.05	62.79	63.33	73.61	62.79
11	76.92	78.05	62.79	63.33	73.61	62.79
Note: S means sample						

The amount of preservative penetrated into wood specimen after adding the solution (Chrome Azurol S) is shown in Fig. 5. The solution reacted with CCB chemicals and forms a dark color zone which showed the length of penetration. Depending on the variation of pressure and duration of treatment time, the penetration is also varied. Due to the mechanical difficulties associated with sealing in pressure chamber and also operating its valves and fluctuation of temperature in seasoning chamber, the penetration of preservative is found at random pattern.

The penetration of preservatives into the wood samples is tested and the results are shown in Figs. 6a, 6b and 6c. Fig. 6a is without treatment and after treatment.

Fig. 6a Wood sample before and after treatment

Fig. 6b shows the treated samples after addition of Chrom azurol solution. The colour and penetration is evident from the figs. Fig. 6c shows the sample after addition of Chrom azurol solution but the samples were not treated with preservatives.

Fig.6b Adding Chrom azurol solution after treatment

Fig. 6c Adding Chrom azurol solution without treatment

VII. CONCLUSION

Wood treatment with preservatives enhances its life that ensures the structural integrity in many exterior applications. Treated wood can withstand fungal decay and insect damage and it is possible to producing a high quality wood product. Necessity of wood in our country is increasing but our resources are limited. Also, the durability is not same for all types of wood species. So that wood preservation process help for better utilization of wood. But sometimes wood preservation process is so expensive which also increase the price of wood. So proper design of a wood preservation system will minimize the price of wood and make it available to all.

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