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Softening and Bending of Black Poplar (*Populus nigra* L.) Wood with Chemicals

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Key words:
Poplar (*Populus nigra* L.) wood, Sodium hydroxide (NaOH), Ammonia (NH_3), Urea (CH_4N_2O), Water, softening and bending.
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ABSTRACT

Black Poplar (*Populus nigra* L.) wood boards (0.8 X 10.0 X 40.0 cm dimensions) were treated with different chemicals; Aqueous solutions of Ammonia (NH_3) 10%, Sodium hydroxide (NaOH) 1% and 5%, Urea (CH_4N_2O) 25%, and water (H_2O) at a temperature of (21-70^{o}C) for (1-24 hours) for bending to a desired shapes. The absorption of chemicals by boards varied with the chemical structure of the used chemicals, treatment temperature and treatment time. The highest absorption of chemicals by wood boards was with aqueous ammonia (NH_3) 10%, then 5% and 1% Sodium hydroxide (NaOH), followed by Urea 25% and water. The treatment temperature increase was effective in improving the absorption of applied chemicals in the case of NH_3 10% and NaOH 1%. The concentration of the chemical (NaOH) also affected the absorption; lower concentration of NaOH (1%) was better than the concentration of NaOH (5%) after one hour of treatment. The bending of wood boards to a desired shape (half circle) achieved at a satisfied level to the local market need with NH_3 10%, and with NaOH (1% and 5%) to a good level. The samples treated with Urea 25% and water failed for bending.

تليين وتشكيل الواح خشب القوغ الاسود بالمعاملة ببعض الكيمياويات

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الكلمات المفتاحية:
القوغ الاسود (*Populus nigra* L.)، هيدروكسيد الصوديوم (NaOH)، امونيا (NH_3)، يوريا (CH_4N_2O)، الماء، تليين وثني.
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الخلاصــة

تمت معاملة خشب القوغ الاسود (*Populus nigra* L.) بمحاليل مائية لبعض الكيمياويات تحت درجات حرارة من 21 – 70 °م لفترات من 1 – 24 ساعة لغرض تطريتها وتشكيلها حسب الحاجة. من نتائج التجربة تبين ان إمتصاص المحاليل الكيميائية تباين مع الكيمياويات المستعملة ودرجات الحرارة ووقت المعاملة. أكثر إمتصاص لنماذج الخشب كان مع محلول الامونيا (NH_3) تركيز 10% وبعده محلول هيدروكسيد الصوديوم (NaOH) تركيز 5% و 1% ثم محلول اليوريا 25% وأخيراً الماء. إن زيادة درجة الحرارة زادت في كمية الامتصاص لمحاليل الامونيا 10% وهيدروكسيد الصوديوم 1% . تركيز الكيمياويات أثر في الامتصاص حيث ان إمتصاص هيدروكسيد الصوديوم أعلى مع تركيز 1% عنه مع تركيز 5% . تم الحصول على تطرية وتشكيل نصف دائرة من النماذج تحت الدراسة بنجاح عالي مع محلول الامونيا تركيز 10% يليه محلول هيدروكسيد الصوديوم بينما لم يتحقق اي نجاح في تشكيل النماذج المعاملة بالماء واليوريا.

INTRODUCTION:

Wood can be made into attractive items with softening and bending treatments. The treatment can result in profitable uses of low grade, not shaped scraps that might otherwise be discarded. Wood bending is an important key in wood constructing for many industries such as furniture's, boats and ships, containers, agricultural tool handles, and sporting goods. There are many methods to make curved wood, the bending process is the one that is efficient, cheapest, and most productive. For the best bending results, we need to consider wood species and the purpose, method for wood seasoning and plasticisation, bending and drying techniques, and effect of bending on wood strength. In order to bend wood, softening with water or chemicals is essential to plasticize wood. When a piece of wood is bent, it is stretched along the outer layer and compressed along inner layer, This stretching will create a stress that pushes back to original shape, so it is important to select the plasticization agent that restrict the development of these stresses. Common chemicals that can plasticize wood include water, urea, dimethyl urea, low molecular weight phenol-formaldehyde resin, dimethyl sulfoxide, and liquid ammonia (Sentance, 2003). Wood can be bent after immersion in those chemicals to a certain limit of the desired shape depends on tree species, retaining of the curved piece to its original shape, and the possibility of sample breaking under bending process, (USDA, 2010). Liquid ammonia appeared as a powerful agent to soften wood strips toward bending into dramatic and complex shapes for permanent application (Schuerch 1964). The experiments carried out by immersing dry wood in liquid anhydrous ammonia at a temperature of -35^{o}C or lower to prevent boiling of ammonia. It showed that it was possible to plasticise wood with anhydrous ammonia at room temperature under an ambient vapour pressure of 145 psi effectively, (Davidson and Baumgardt 1970). It found that the diffusion of liquid ammonia is faster than water, which makes the sorption more powerful and speeds the swelling of wood, (Bariska and Schuerch, 1977). Liquid ammonia swells both cellulose and lignin (major wood components), and change crystalline structure of cellulose, (Young 2007). In addition, the straight chains of cellulose shrink and slack when wood is treated with temperature and chemicals and helps to bend wood, (Hon and Shiraishi, 2001). As the ammonia evaporates, the lignin resets the wood stiffens and retains its new shape.

The mechanism of wood plasticization was understood as the added solution (Plasticizer) enters between the cellulose chains, separating the adjacent polar groups; weakens the cross links; and acts as a molecular lubricant, so, the desired shape can be formed. However, the temporary plasticization of wood, using steam as plasticizer was of more interest and has been applied before to a certain limit, then new method of plasticization using liquid ammonia to bend wood into desired shapes. These applications of liquids as plasticizers overcome the problem of wood cellular structure. The mechanism of liquid ammonia plasticization of wood relates to its solvent characteristics for both lignin and polysaccharides systems of the cell walls in which liquid ammonia swells both systems (Schuerch 1964). There is a temporary alteration of physical and mechanical characteristics of wood due to liquid ammonia plasticization but the alteration disappeared when ammonia evaporates and the new hydrogen bonds formed. Alkali chemicals used for wood softening; including sodium hydroxide, (Hashimoto 1995). The softening solvents vary in the degree of flexibility of the bended wood products and the ease with which they removed. Wood softening for bending was softening liquid composition, treatment temperature, and treatment time dependent. (Hillis, 1984, Shape, 2010). Softening of lower density wood such as willow and poplar for bending requires short time treatment, (Randy and Rao, 1995). Other methods dealing with decrease of viscosity of the main connecting substance between cellulose and lignin. Hot pressed and microwave plasticising technique was used to soften wood, (Reiniatti, 2009, Gasparik and Caff, 2013).

This study planned to investigate the possibility of wood softening with different chemicals in aqueous solution, treatment temperature, and treatment time to achieve the highest softening and bending of wood board to half circle shape without changes of its identity and properties. The bending of wood to half circle and other shapes is required by local markets to reduce the wood machining wastes in making furniture’s and other products, and to improve the utilization and applications of the local wood sources.

MATERIALS AND METHODS :

The experiment was carried out on (0.8 × 10.0 × 40.0 cm) dimensioned wood boards; they were sawn from black poplar *(Populus nigra* L.*)* wood of defects free and air-dried trunks. The moisture contents of the boards were determined (12-14%). They immersed in different aqueous solutions of urea (CH_4N_2O) 25 %, NaOH 1 % and 5 %, NH_3 10 %, and water for specified time of 1-24 hours at different temperatures (21-70^{o}C). At the end of the treatment time the samples were taken from the solution and the weight was recorded for the absorbed amount of solution, then the bending process using a device in the local wood market (was to form half circle). The boards response to the bending and their situation after leaving the bending device were recorded, they left for air-drying for one week. To optimize the treatment variables for highest results, the concentration of NaOH (based on weight) was increased to 5%, the treatment temperature was also increased to 70^{o}C with NaOH solution. The treatment time was varied from 1-24 hours. The experiment was conducted at the labs of Forestry department/Mosul University and Mosul local wood market. The results throughout this study were based on two boards for each treatment. The evaluation of the results was based on the followings:

1. Half circle formed shape.
2. Cracks or break of the board after bending.
3. Formed shape stability (return to the original shape or not).

RESULTS and DISCUSSIONS:

The softening of the black poplar wood boards results are given in Tables 1 and 2 and in Figure 1, based on the absorption of the applied chemical solutions which was used as an indication for the extent of bending possibility.

Chemicals and bending

The results in Table 1, showed that aqueous NH_3 10 % and aqueous solution of NaOH 1% and 5% were at the highest absorption values at 70^{o}C; 106.39-167.10 % with NH_3 10 % and 68.94-157.53 % for both 1% and 5% NaOH, while urea 25% and water with lower values; 36.79-129.49 % and 57.75-112.17% respectively. In which the chemicals with better ability to form hydrogen bonds with the wood components affected the absorption by the wood boards.

Table 1. Different chemical solutions absorption of wood Samples at 70^{o}C, based on weight increase difference (%)

Treatment Time (hrs.)	H_2O	NH_3 10%	Urea 25% CH_4N_2O	NaOH 1%	NaOH 5%
1	57.75	106.39	36.79	68.94	82.77
2	61.41	115.02	42.50	111.16	92.86
3	70.50	133.65	46.50	118.27	94.67
4	74.80	141.00	62.20	136.41	96.00
20	89.04	155.19	121.77	147.48	111.74
24	112.17	167.10	122.49	157.53	116.16

The bending trials showed a failure to get the desired shape (half circle shape) with the application of urea 25% and broken samples with water; the samples treated at 70^{o}C for 1-24 hours by immersing in the aqueous solutions. However, treating wood boards with aqueous NH_3 10% and NaOH, for 1- 4 hours did not get the exact shape even the absorption of NH_3 and NaOH was high (Table 1). The highest bending results achieved with 24 hours of immersing in the aqueous solutions of NH_3 10 % and NaOH of 1% and 5%, (Figure 1).

From Figure 1, it can be seen that the trials with water did not give any softening which is appeared in the way the board failed in the device for bending, it was just broken straightly without any bending. While with the urea there was some bending but the board broke later. In the case of

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Sodium hydroxide, there was softening to good limit to achieve bending but not satisfied. The best result was with Ammonia in which the softening was achieved and the bending to the desired shape satisfactorily achieved.

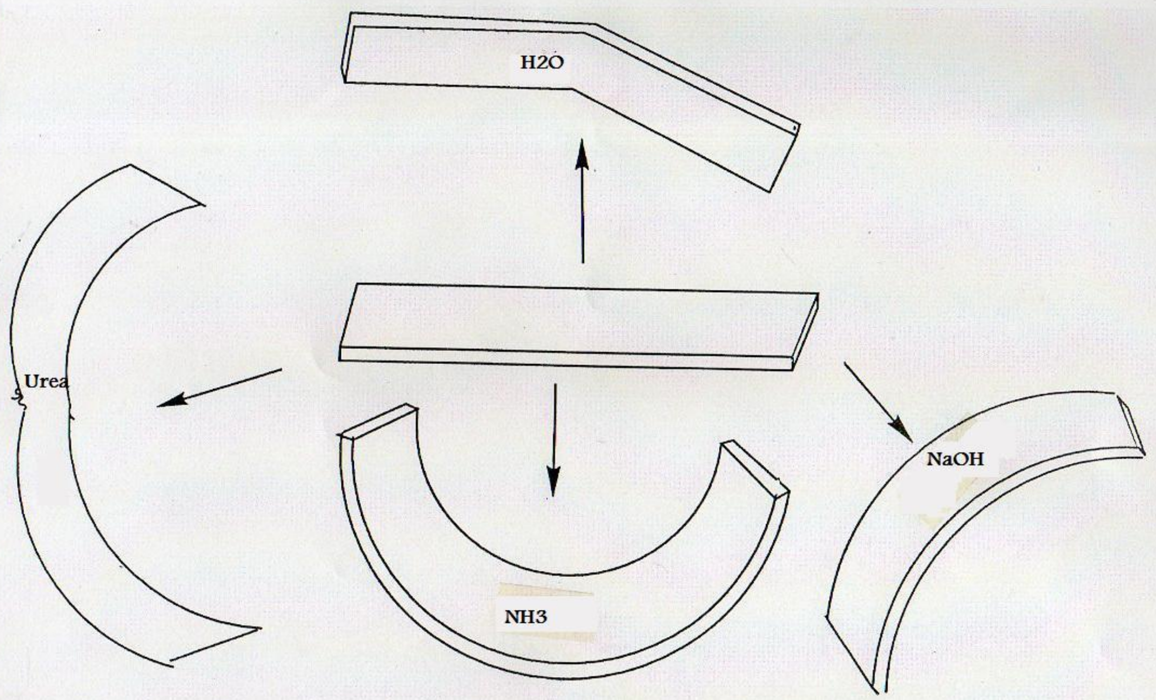

Figure 1. Desired wood shape formed or failed with different chemicals

The stability of the formed shape checked after 4, 8, and 12 weeks after the treatment, the shaped board left in an opened air conditions in the mill. The formed shapes with NaOH 1% and 5%, and NH_3 10% were stable throughout all the time after the treatment.

There are significant differences between applied chemicals in the bending of the boards in this experiment, which can be related to the molecular interactions between wood polymers; cellulose, hemicelluloses and lignin and different solvents applied. The swelling of wood enhanced with increase in hydrogen bonding capacity of the applied solution (Rowell 1984). However, the differences between the applied solutions in this experiment and the bending results to the desired shape may be affected by different hydrogen bonds capacities of the solutions, in which they expected to swell and soften the wood differently. The urea structure in which there is hydrogen atoms connected with Nitrogen, there is possibility to form hydrogen bonds but the tendency of hydrogen atoms to leave the structure of the urea is slower than with ammonia and Sodium hydroxide, it could be the absorption of urea and water is lower than ammonia and Sodium hydroxide. The penetration ability of the used solutions into the wood structure is another factor affected by the crystalline of cellulose and organization of the three wood polymers.

Solution concentration:

The change in the solution concentration affected the treated wood boards by increasing of the absorption with the increase of the solution concentration as can be seen in Table 1 in the first hour then it slowed down later. The increase of NaOH concentration up to 5% in its aqueous solution resulted in higher absorption 82.77% compared to 68.94% for NaOH 1% at 70^{o}C in the first hour of the treatment., The shaping of wood samples was good with both concentrations and it was little better with NaOH 5%.

The increase of solution absorption by wood samples as a result of concentration increase is related to the increase of the number of NaOH molecules to bind with wood polymers and to displace hydrogen bonding in the structure of wood. This case was observed at the first few hours then it slowed down due to the spreading in deep thickness of the wood pieces in which it is affected by swelling and moving of NaOH molecules in more depth in the wood with alteration by OH^- groups that available from both NaOH and water since it has more OH^- groups from water in low concentration of NaOH.

Treatment temperature:

The treatment temperature increase was effective in increasing of the solution absorption and the improvement of the wood samples as given in Table 2. The absorption of aqueous ammonia (10%) at 21^{o}C was 26.18-91.23% and it was increased to 106.39-167.10% with the temperature increase to 70^{o}C and same trend of change appeared with temperature increase with NaOH 1%.

Table 2. Treatment Temperature and absorption of wood samples, Based on weight increase difference (%).

Treatment Time (hrs.)	NH_3 10%		NaOH 1%	
	21^{o}C	70^{o}C	21^{o}C	70^{o}C
1	26.18	106.39	27.26	68.94
2	33.76	115.02	32.78	111.16
3	37.85	133.65	37.90	118.27
4	42.04	141.00	41.51	136.41
20	69.89	155.19	68.41	147.48
24	91.23	167.10	69.71	157.53

The treatment temperature affects hydrogen bonding of wood polymers (cellulose, hemicelluloses, and lignin), and solution penetration in the wood structure. The temperature increase enhances hydrogen bonding formation and movement, swelling, and plasticizing of wood (Schuerch 1964). The solution-wood interaction affected by the treatment time and temperature increase, the penetration and swelling of wood was increased with the time increase at same temperature, which is due to longer contact between the solution and wood to form new bonds and penetrate more solvent into wood structure.

Softening and shaping of poplar wood using aqueous solution of chemicals such as sodium hydroxide (NaOH) 1% and 5%, Ammonia (NH_3) 10%, urea (CH_4N_2O) 25% and water resulted in changing of wood ability to absorb chemical solution and its softening toward shaping to a desired shape. The application of aqueous solutions of NH_3, NaOH 1% or 5% at 70^{o}C showed that the wood samples shaping into the desired shapes was acceptable more than other applied chemicals in this study. However, the treatment temperature increase to 70^{o}C improved absorption and softening of the treated samples, and same results achieved with concentration increase of NaOH but to a limited extent. The samples treated with ammonia gave good results of shaping compared with other chemicals. Ammonia solution penetrates the lignin fraction of plant cell and swells cellulose then gets into crystal lattice of cellulose in which it causes a change in the structure of wood components. The ability of hydrogen bonding disruption and breaking of both amorphous and crystalline regions of the polysaccharides in the cell wall and within the lignin matrix. Liquid ammonia in this case causes a softening of wood fibres and allows the flow of macromolecules leading to tension or compression. Longer treatment time will cause deacetylation of hemicelluloses when ammonia evaporates and new hydrogen bonds will form a new positions. There are some cross-linking that happen to keep the permanent position of bending, (Schuerch, 1964). This study needs more investigation of the treated wood samples mechanical properties and extend to other wood species. This study focused on treating the black poplar wood boards with chemicals under different treatment temperatures and time and also the concentration of Sodium hydroxide (NaOH) was changed to study the effect of concentration. The finding of this study showed that the chemical type is important and the increase of treating time and temperature improved the absorption of the applied chemicals. Aqueous ammonia (NH_3) of 10% showed highest absorption with time and temperature combination and gave the required bending to half circle of the treated boards. The Sodium hydroxide (NaOH) at concentration of 1% achieved high absorption with treating time and temperature and also came closer to ammonia in shaping of the samples. The ease of handling treated boards with aqueous ammonia with treating time and temperature in this study attracted our attention to use it for commercial scale after some studies to find out more suitable treating conditions over other chemicals used in this study.

REFERENCES:

Bariska, M. And C. Schuerch. (1977). Wood softening and forming with ammonia. ACS Symposium series, Vol.43:326-347.

Davidson, R., and Baumgardt, W. (1970). Plasticizing wood with ammonia. Forest Products J. **20**: 19-25.

Gasparik, M. and Caff, M. (2013). Identification of factors influencing the maximum flexure of beach wood plasticized by microwave heating. Cellulose Chem. Technol. 47(7-8):573-581.

Hashimoto, H. (1995). Softening of woody materials and developing of compound materials. Study on softener. Shiken kenky Hokoku, Fukushima-ken haiteku Puraza, PP:180-186.

Hillis, W.E. (1984). High temperature and chemical effects on wood stability. Part 1. General consideration. Wood Science and Technology 18:281-293.

Hon, David N-S. And Shiraishi, N. (2001). Wood and cellulose chemistry, 2nd. Edition. Revised and expanded. Marcel Dekker Inc. N.Y.

Randy, C.N. and Rao, P.V.K. (1995). Wood softening and bending with ammonia. J. Wood news. 5(1):29-31.

Reiniati, I. (2009). Chemical, physical, and viscoelastic properties of hot-pressed hybrid poplar. M.Sc. thesis. Washington State University, WA, USA.

Rowell, R. (1984). The chemistry of solid wood. American Chem. Society, Washington D.C.

Shape, T.F. (2010). Stability and bending of wood for the hobbyist. Lousiana State University Agricultural Centre. Publication number 2643.

Schuerch, C. (1964). Principle and Potential wood plasticization. Forest Products J. 14: 377-381.

Schuerch, C., Burdick, U. and Mahdalik, M. (1966). Liquid ammonia-solvent combinations in wood plasticization. Chemical treatment. Ind. And Eng Chem Prod and Dev. 5:101-105.

Sentance, B. (2003). Wood-the world of wood work and carving. Thomas and Hudson Ltd. London.

USDA. (2010). Wood as Engineering Material Part 1: Bending and Plasticizing wood: In USDA Wood Handbook. USDA.

Young, R. (2007). Wood and Wood Products: In Handbook of Industrial Chemistry and Biotechnology. Edited by Kent J., Riegel E. Springer Science and Business Media, L.L.C.