INTERNATIONAL JOURNAL OF
MULTIDISCIPLINARY STUDIES IN ARCHITECTURE AND CULTURAL HERITAGE
VOLUME 5, ISSUE 1, 2022, 135 – 139.

Evaluation of using Klucel G on the Physical properties of sycamore wood

Mahmoud Hassan Sallam

Conservator, Ministry of Tourism and Antiquities

Mohamed Marouf

Conservation Department, Faculty of Archaeology,
Sohag University, Egypt

Nesreen El Hadidi

Conservation Department, Faculty of Archaeology,
Cairo University, Egypt

Maysa Mohamed Ali

Conservation Department, Faculty of Archaeology,
Cairo University, Egypt

Abstract

Wood was used in the past in many industries in daily life, including wooden coffins, in which many local woods were used. These woods were affected by various damage factors such as high temperatures and humidity, which led to the weakening of these woods and made them vulnerable to the appearance of various deterioration aspects.

Several consolidating materials were used to improve the physical and mechanical properties, as the study sheds light on the use of Klucel G, as it is one of the best materials used in the recent consolidation of archaeological wooden objects, which gave satisfactory results, klucel G concentration ,05 % and Klucel G concentration 05 % with Nano paraloid concentration 1% by dissolving it in ethyl alcohol (ethanol), Visual assessment and several analytical techniques were used for the evaluation of the selected consolidate material . The analytical techniques are Scanning Electron Microscope (SEM), Color change and Measurement of physical Properties (Color Change CIE Lab, Density, Porosity and Water Absorption) . The results obtained from Color change revealed that Klucel G 0.5% gave the level of total color differences (ΔE) KG1A and KG1AA with 2.38 and 1,69 respectively compared to the standard sample STA gave 1.24 . The Density (g/cm3) to Klucel G 0.5% They are (KG1A) and (KG1AA), which results in (0.443 g/cm3) and (0.413 g/cm3), respectively, have the highest density compared to the density of the rest of the samples of other materials and compared to the standard sample STH (0.425 g/cm3).

Key words:

Ficus Sycomorus, Physical Properties, Klucel G, Density, Porosity.

1. Introduction

Consolidation is an important process in the conservation of various materials including wood. Application of synthetic resin solutions is a generally accepted consolidation technique for wood, since a solid polymer can fully or partially fill the voids resulting from degradation, thus repairing the material's integrity and improving its physical and mechanical characteristics [1-2] . The development of new materials and methods for consolidation to improve the efficiency of treated materials is a subject of worldwide interest in conservation research [3] . reported that even though wood consolidated by synthetic and natural chemicals has considerably greater strength than unconsolidated wood.

From this point, the researchers used this technique in conducting an experimental study of the effect of using some traditional materials alone, which gave good results with similar materials, such as Hydroxypropyl cellulose (Klucel G) that was used widely as a good consolidation material of pigment material [4], Conservators have frequently used Klucel G for the consolidation of matte paint, and other grades have been used in poultices, inpainting media, and infilling media.It has also been used by many researchers such as (Henry, Walter, et al.1993) who state that Klucel-g can be used successfully in water/alcohol solutions to consolidate pigmented ethnographic materials which have a matte surface quality, also it has been used in ethanol to consolidate darker colors like the blues and browns of water-based paints which are sensitive(i.e. darken) with aqueous consolidates [5], Mahony (2014) also refers that it gave good results when it was used to strengthen the organic protein substances by dissolving it in the organic solvents, it did not work to cause a major color change and helped to preserve the natural appearance of the archaeological material [6] .

Paraloid B-72 is stable and non-yellowing acrylic resin chemically is a copolymer of ethyl methacrylate and methyl acrylate with a molar ratio of approximately 70-30%. It can be applied for bone conservation [7]. Paraloid is considered one of the acrylic resins most frequently used in the consolidation of artifacts due to its characteristic mechanical properties and ease of use. Therefore, using a polymer requires dis- solving it in a solvent, such as acetone or toluene [8-9] .

This study aims to examine the efficiency of Klucel G and polymeric Nano Paraloid in the treatment and preservation of Wood objects. Evaluating the changes in a certain Wood sample property before and after artificial aging.

2. Materials

2.1. Preparation of wood samples

The wooden samples were prepared from the same type of wood used in the manufacture of the coffin, which is sycamore wood, where the samples were cut into cubes of dimensions (5 x 5 x 5 cm) according to British specifications [10] , as shown in Fig No. (1), Standard specifications for aging: Since there is no standard specification for thermal aging of wood, the standard specification for paper made from wood pulp has been used due to the similarity of chemical compounds between them: (temperature 80 ° C and relative humidity 65%) (BS 6388-3:1996 - ISO 5630 -3:1996, Paper and board - Accelerated aging - Part 3: Moist heat treatment at 80 degrees C and 65 % relative humidity Paperback), Exposure time: Aging for 120 hours (5 days) continuously The equivalent of 25 years in natural conditions, and Lamp type: Mercury-ARC Lamp (E40 - Mix F 500 W) was used. Standard specifications for aging: Light aging was used for 120 hours (5 days) continuously [11] .

The samples were divided into 11 samples: (ST) standard sample, (STA) standard thermal aging sample, (STL) standard photo aging sample, (KG1A) klucel G 0.5% sample , (KG1AA) klucel g 0.5% thermal aging sample, (KG1L) klucel g 0.5% sample, (KG1LL) klucel G 0.5% photo aging sample, (KGP1A) klucel G 0.5% + Nano paraloid 1%sample, (KGP1AA) klucel g 0.5% + Nano paraloid 1% thermal aging sample, (KGP1L) klucel g 0.5% + Nano paraloid 1% sample and (KGP1LL) klucel g 0.5% + Nano paraloid 1% photo aging sample

Fig No. (1) shows the shape of the samples used in the experimental side of the study

2.2. Preparation of klucel G

Klucel G was prepared at concentrations of (0.5%) by dissolving it in ethyl alcohol (ethanol). By adding a certain volume of Klucel G to the ethyl alcohol to reach the desired concentration. As for the Nano-paraloid at a concentration (1%), Paraloid B72 was prepared as a co-polymer of methyl methacrylate/ethyl acrylate (MMA/EA) monomers (Aldrich, Darmstadt, Germany) with a composition ratio of 70/30. It was prepared by solution polymerization technique with solid content 1% as a pure copolymer. The polymerization was carried out according to the following procedure: in a 250-mL three-nicked flask, the desired amount of the monomers with the selected composition ratio (70/30 MMA/EA), was stirred with Ethanol for 30 min at room temperature using a mechanical stirrer (500 rpm). In addition, the presence of 0.005 g of Klucel G. Then, the mixture was heated to 80 ºC. Then, the initiator potassium persulphate (PPS) (0.27 g) (Sigma-Aldrich, Schnelldorf, Germany) dissolved in 50 mL of Ethanol and Sodium dodecyl sulphate (SDS) as emulsifier dissolved in 45 mL of Ethanol was added to the reaction mixture under continuous stirring for 3 h to obtain the solutions of Paraloid B72/ Klucel G[12] .

3. Methods

3.1. Scanning Electron Microscope (SEM).

A scanning electron microscope was used MODEL: **JEOL JSM 5400LV EDX Link ISIS-Oxford "high vacuum,** The aim of this examination is to identify the surface changes of sycamore wood before and after strengthening and aging processes**.**

3.2. Measurement of physical properties (Color Change CIE Lab, Density, Porosity and Water Absorption).

3.2.1. Measurement of Color Change CIE Lab

An Optimatch 3100 ® from the SDL Company was used to measure color change. This procedure was carried out at the National Institute of Standards, Al-haram, Giza, Egypt.

The wood is characterized by its colors ranging from light colors that reach white in some types of wood, to dark colors that reach dark brown and black in other types. Wood colors are easily affected by ambient changes, whether by changes in temperature, humidity, or chemical treatment of wood. The process of measuring the color change of wood is one of the important operations in the field of wood treatment and maintenance in order to identify the degree of wood color change before and after adding different treatment and maintenance materials in order to determine the best one

The chromaticity change of wood samples is measured using the CIE lab system[13] .It is an abbreviation of the French sentence (Commission Internationale de l'Eclairage) which is an international systemDepends on the symbols (L*-a*-b*-ΔE) [14] , as shown in Fig No (2)

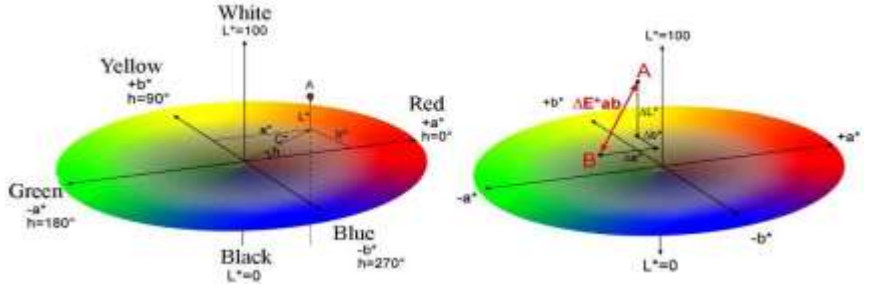

Fig No(2) shows the color degrees of the symbols (L*-a*-b*-ΔE) in the (CIE) system[15]

The extent of the color change between two samples is measured by comparing the values of L0- a0*-* b0*) in the standard sample and the values of L1* - a1*- b1*) in the sample whose color change is to be identified. The colorimeter gives a colorimeter. These values are for each sample [16-17] .

3.2.2. Measurement of (Density, Porosity and Water Absorption)

These tests were conducted to find out the changes before and after the strengthening and aging processes, where the tests were applied to samples with dimensions (5 x 5 x 5) and the samples were immersed for 24 hours in distilled water at room temperature and weighed before and after the immersion operations according to [18-19-20-21] ,below are the tests that were done:

- **Density**

Density = ((g) mass)/((cm3) volume) [22-23] :

m2 x h x i

Since the shape of the samples is a cube, the volume was determined by the following formula: length x width x height

The volume = 5 x 5 x 5 = 125 cm3

- **Porosity**

(A.P) in % was defined in the following Equation: [24-25]

$$\text{Porosity (PT)} = \frac{\text{Pore Volume (VP)}}{\text{Total Volume (VT)}} \times 100$$

Where: W1 and W2 is dry and wet weight in g and V is the volume in cm3

- **Water Absorption**

(W.A) in % was determined in the following Equation:

$$\text{Water saturation} = \frac{(\text{immersion before the sample mass} - \text{immersion after the sample mass})}{(\text{immersion before the sample mass})} \text{x100} = \%$$

Where: W1 and W2 is dry and wet weight in g [26].

4. Results and Discussion

4.1. Scanning Electron Microscope (SEM).

Fig (3) Shows the SEM images a magnification of 200x of Klucel g 0.5% and Klucel g 0.5% / Nano Paraloid B-72 1% thermal aging . (A) Standerd sample ST, (B) Thermal sample STA, (C) KG1A sample, (D) KG1AA sample,(E) KGP1A sample, (F) KGP1AA sample

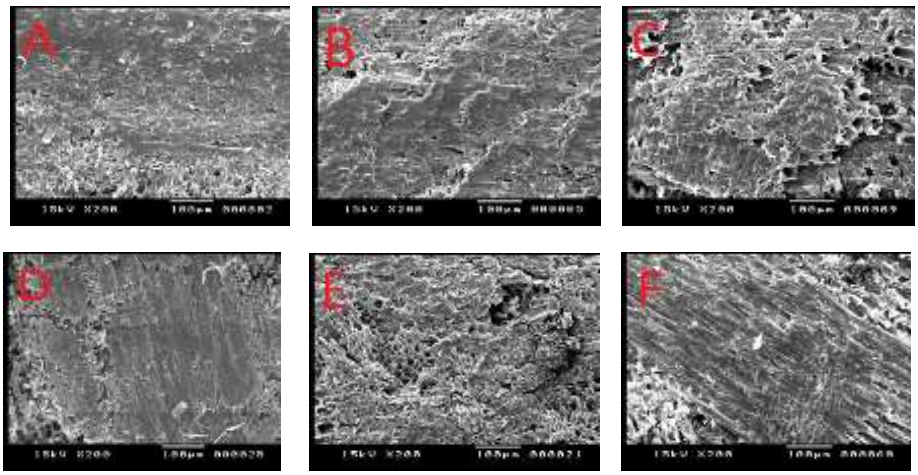

Figure No. 3 shows the scanning electron microscope examination of Klucel G samples with a concentration of (KG1AA) klucel g 0.5% thermal aging sample, and (KGP1AA) klucel g 0.5% + Nano paraloid 1% thermal aging sample for thermal aging samples before and after hardening and after thermal aging and comparing the samples through the surface changes that occurred on the surface of the samples and the extent of the penetration of the consolidate material. After its application, as well as after thermal aging, this is due to the stability of the concentration of klucel G to the temperatures, as well as the absence of any gloss produced on the surface of the samples after the application of klucel G.

Fig (4) Shows the SEM images a magnification of 200x of Klucel g 0.5% and Klucel g 0.5% / Nano Paraloid B-72 1% photo aging . (G) Photo sample STL, (H) KG1L sample , (I) KG1LL sample, (J) KGP1L sample,(K) KGP1LL sample

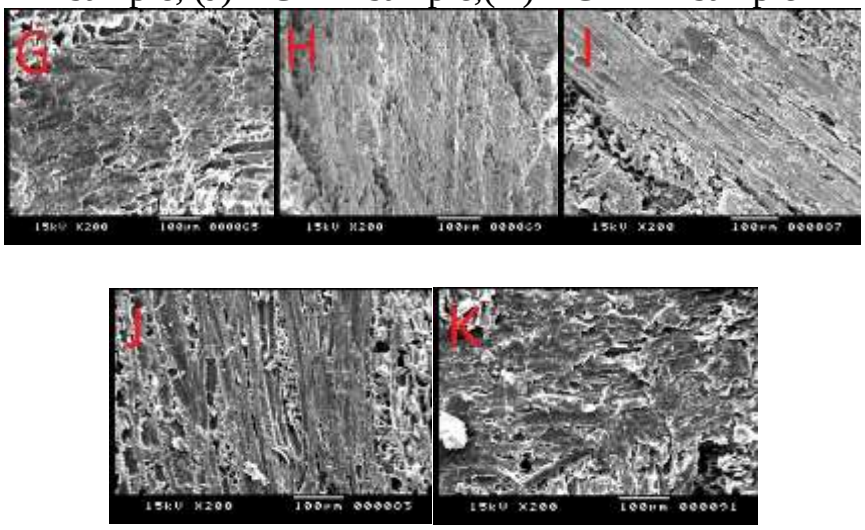

Figure No. 4 shows the scanning electron microscope examination of Klucel G samples with a concentration of (KG1LL) klucel G 0.5% photo aging sample and Klucel G 0.5% + Nano paraloid 1% sample for photo aging samples before and after hardening and after photo aging and comparing the samples through the surface changes that occurred on the surface of the samples and the extent of the penetration of the consolidate material. After its application, as well as after photo aging, this is due to the stability of the concentration of Klucel G to the light, as well as the absence of any gloss produced on the surface of the samples after the application of Klucel G.

4.4.1. Measurement of Color Change CIE Lab

Table No. (1) shows color change tests for standard and heat aging samples

M	S	L	A	B	ΔL	Δa	Δb	ΔE
1	ST	64.07	2.04	10.13	-	-	-	-
2	STA	65.24	1.85	9.76	1.17	− 0.19	− 0.37	1.24
3	KG1A	65.86	2.31	11.67	1.79	0.27	1.54	2.38
4	KG1AA	65.24	1.14	10.62	− 0.62	− 1.17	− 1.05	1.69
5	KGP1A	60.64	2.06	10.58	−3.43	0.02	0.45	3.46
6	KGP1AA	61.82	1.87	10.99	−2.25	−0.17	0.86	2.41

Through the previous, it is clear that the values of (ΔE) from samples (KG1A), (KG1AA) and (KGP1AA), whose values were (2.38), (1.69) and (2.41), respectively, which gave a clear color change. The values of (KGP1A) samples were (3.46), respectively, which gave a total color change in an unobservable medium, From the previous results, it is clear that the best values (ΔE) for the total change of samples for thermal aging are klucel g samples with a concentration of 0.5%, Where the results came from sample (KG1A) and it was (2.38) and sample (KG1AA) and it was (1.69), which caused a total change of the samples in a slight and unnoticeable way compared to the rest of the samples for the other materials and the standard samples ST and STH.

Table No (2) shows the chromatic change tests for the standard and photo aging samples

M	S	L	A	B	ΔL	Δa	Δb	ΔE
1	ST	64.07	2.04	10.13	-	-	-	-
2	STL	62.21	1.79	9.61	− 1.86	− 0.25	− 0.52	1.95
3	KG1L	67.04	1.63	10.99	2.97	− 0.41	0.86	3.12
4	KG1LL	62.27	1.65	10.11	− 4.77	0.02	− 0.88	4.85
5	KGP1L	66.57	2.19	11.74	2.50	0.15	1.61	2.98
6	KGP1LL	63.96	1.58	11.39	− 0.11	−0.46	1.26	1.35

From the previous table it becomes clear the values of (ΔE), the samples (KGP1L) and (KGP1LL) had values of (2.98) and (1.35), respectively, where the samples gave a color change. Slightly and unnoticeably total, while the samples (KG1L), (KG1LL), their values were (3.12) and (4.85), respectively, where the samples gave a total color change in an average manner. and unnoticeable, From the previous results, it is clear that the best values (ΔE) for the total change of the samples due to thermal aging are samples of Klucel G concentration of 0.5% + Nano paralloid of concentration of 1% Where the results were sample (KGP1L) and it was (2.98) and sample (KGP1LL) and it was (1.35), which caused a total change of the samples slightly and not noticeably compared to the rest of the samples for other materials and the standard samples ST and STL.

4.4.2. Measurement of (Density, Porosity and Water Absorption)

Table No. (3) shows the proportions of the samples to calculate the density, porosity and water saturation of the samples compared to the standard sample

M	S	Sample volume Before immersion (g)	Sample volume After immersion (g)	Void Volume (g)	Porosity (%)	Water Absorption (%)	Density (g/cm3)
1	**ST**	64.03	113.67	49.64	77.52	43.67	0.512
2	**STH**	53.23	91.70	38.47	72.27	41.95	0.425
3	**STL**	54.20	96.44	42.24	77.93	43.79	0.433
4	**KG1 A**	55.49	96.79	41.30	74.42	42.66	0.443
5	**KGP 1A**	51.72	89.19	37.47	72.44	42.01	0.413
6	**KG1 AA**	49.83	94.08	44.25	88.80	47.03	0.398
7	**KGP 1AA**	51.36	82.72	31.36	61.05	38.12	0.402
8	**KG1 L**	53.14	89.29	36.15	68.02	40.48	0.425
9	**KGP 1L**	51.90	91.35	39.45	75.91	43.15	0.415
10	**KG1 LL**	53.28	90.83	37.55	70.47	41.34	0.426
11	**KGP 1LL**	51.00	88.65	37.65	67.84	39.05	0.408

Through the previous table No. (3), which clarified the density of samples for thermally aging samples and compared them with the standard sample STH, it was found that the samples of **Klucel G** were 0.5% They are (KG 1A) and (KG1AA), which results in (0.443 g/cm3) and (0.413 g/cm3), respectively, have the highest density compared to the density of the rest of the samples of other materials and compared to the standard sample STH (0.425 g/cm3). As for the density of the optically aging samples and their comparison with the standard STL sample, it was found that the samples of Klucel G concentration of 0.5%, namely (KG1L) and (KG1LL), whose results were (0.425 g/cm3) and (0.426 g/cm3), respectively, are the highest density compared Density of the rest of the samples of other materials and compared to the standard sample STL (0.433 g/cm3).

Through the previous table no. (3), it is clear that the samples of **Klucel G** materials with a concentration of 0.5 + Nano-paralloid at a concentration of 1% for the thermal aging samples gave the lowest rates of porosity compared to the samples of other materials and the standard sample, where the results of the samples are as follows: The result of the sample (KGP1A) gave 72.44%, while (KGP1AA) sample 61.05%,

From the previous table (3), it is clear that the samples of Klucel G materials with a concentration of 0.5% + Nano paralloid at a concentration of 1% for the thermal aging samples gave the lowest percentages of water saturation compared to the samples of other materials and the standard sample, where the results of the samples are as follows: The result of the sample (KGP1A) gave 42.01%, while (KGP1AA) sample 38.12%, while samples of Klucel G materials of 0.5% concentration + Nano-paralloid concentration of 1% for the photo aging samples gave the lowest porosity ratios compared to the samples of other materials and the standard sample where the results of the samples are as follows:(KGP1L) 43.15%, while the sample (KGP1LL) 39.05%.

5. Conclusion

Many archaeological wood and coffins are exposed to many different damage factors that cause severe damage to wood, which through the stages of treatment and wood conolidation to treat the existing weakness, using Klucel G in its concentrations. It was found that the Klucel G concentration 0.5% gave good results in the color change and the occurrence of a total color change, From the previous results, it is clear that the best values (ΔE) for the total change of samples for thermal aging are klucel g samples with a concentration of 0.5%, Where the results came from sample (KG1A) and it was (2.38) and sample (KG1AA) and it was (1.69), which caused a total change of the samples in a slight and unnoticeable way compared to the rest of the samples for the other materials and the standard samples ST and STH, as well as improving the physical properties of the samples after treatment, whether it was in density, porosity and water absorption.

6. References

1. **Henriques DF, Nunes L, Brito J (2010);** Performance of Paraloid B72 combined with the application of biocides on wood degraded by fungi. In: Proceedings of 4th international conference on wooden cultural heritage: interaction between wood science and conservation of cultural heritage, COST Action IE0601, Izmir Turkey.

2. **Traistaru AAT, Timar MC, Campean M, Croittoru C, Sandu I (2012);** Paraloid B72 Versus Paraloid B72 with nano-ZnO additive as consolidants for wooden artifacts. Mater Plast 49(4):293–300.

3. **Clausi M, Crisci GM, Russa MF, Malagodi M, Palermo A, Ruffolo S. A, (2011);** Protective action against fungal growth of two consolidating products applied to wood. J Cult Herit 12:28–33.

4. **Feller, F.L and Wilt, M. (1993)**; Evaluation of cellulose ethers for conservation, The Getty conservation institute. United States of America. Second printing.

5. **Hamed, S. and Hassan, M.L. (2019)**; A new mixture of hydroxypropyl cellulose and nanocellulose for wood consolidation. Journal of Cultural Heritage. Vol. 35, pp.140-144.

6. **Hala A.M. Afifi, Rushdya Rabee Ali Hassan, and Shimaa M. Menofy, (2021),** AN EXPERIMENTAL STUDY FOR CONSOLIDATION OF ARCHAEOLOGICAL CARTONNAGE USING KLUCEL G AND CHITOSAN 51 SCIENTIFIC CULTURE, Vol. 7, No 2, pp. 49-68.

7. **Mostafa Samir Abo El-Hassan, Mohamed Marouf, Wael Sabry , (2021) ;** Utilization of Paraloid / Titanium dioxide nano composite in the Consolidation of Archaeological Bone, INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY STUDIES IN ARCHITECTURE AND CULTURAL HERITAGE VOLUME 4, ISSUE 2, pp. 99 – 122

8. **J., Leuninger, F., Tiarks, H., Wiese, B., Schuler, Wassrige Nano Komposite. Farbe & Lack 10/2004** S. 30 http://www.european-coating. com.

9. **Vinçotte, A., Beauvoit, E., Boyard, N., Guilminot, E. (2019)**; Effect of solvent on Paraloid ® B72 and B44 acrylic resins used as adhesives in conservation. Heritage Science, Vol. 42, No. 7, pp.1-9.

10. **B S. British Standard**, Institutions. 1956. British Standard Institutions, British Standard Methods for Testing Small Clear Specimens of timber, No. 373. London.

11. **Arias, T. E, et al. 2013**. "Conservation of Historic Book Bindings by Means of Facsimile Reproduction: The Torres Notarial Register (1382–1400) in the Archive of the Royal Chancellery of Granada, Spain." Science and Technology for the Conservation of Cultural Heritage 227-230.

12. **Mohamed Moustafa Ibrahim , Wael Sabry Mohamed, and Hamdy Mohamed Mohamed, (2021)** ; EXPERIMENTAL STUDY FOR EVALUATION OF PARALOID® B72 AND ITS NANOCOMPOSITE WITH NANO TiO2 AND NANO ZnO FOR CONSOLIDATION OF POTTERY SAMPLES, SCIENTIFIC CULTURE, Vol. 7, No. 2, pp. 101-111.

13. **Sundqvist, P. 2004**. Color Change and Acid Formation in Wood During Heating. Skellefta Sweden: Doctoral Thesis Lulea Universty of Technology. P24.

14. **CIE Standard 15 . 2004**. Technical Report: Colorimetry, 3rd edition. Technical Report, Washington. USA: International Commission on Illumination. P28.

15. **Persson, M S. 2005**. Properties of Solid Wood Responses to Drying and Heat Treatment. Department of Skellefteå Campus, Division of Wood Science and Technology: Luleå University of Technology. P40 .

16. **Matsuo, M. et al. 2012**. "Color Changes in Wood During Heating: Kinetic Analysis by Applying Time{Temperature Superposition Method." Applied Physics 99, 47−52.

17. **Kubovský, I. 2013**. "Changes of the Wood Surface Colour Induced CO2 Laser and its Durability After the Xenon Lamp Exposure." Wood Research 58 (4), 581-590.

18. **Sanae Mori , Akira Itoh , , Satoshi Nanami , Sylvester Tan ، Lucy Chong and Takuo Yamakura, (2014);**Effect of wood density and water permeability on wood decomposition rates of 32 bornean rainforest trees, Journal of Plant Ecology, Volume 7, Number 4، pp. 356–363 . doi:10.1093/jpe/rtt041.

19. **Hayashi S, Nishimoto K (1965)** ; Studies on the water permeability of hardwoods. Mokuzai Kenkyu 35, pp.33–43.

20. **Ajibola B. Oyedeji , Olajide P. Sobukola, Ezekiel Green1 & Oluwafemi A. Adebo,(2021) ;** Physical properties and water absorption kinetics of three varieties of Mucuna beans, Scientific Reports 11:5450 https://doi.org/10.1038/s41598-021-85087-8.

21. **Baryeh, E. A. (2001)** ; Physical properties of bambara groundnuts. J. Food Eng. 47(4), pp. 321–326.

22. **A. B. Oyedeji , O. P. Sobukola, E. Green1 & O. A. Adebo** " Physical properties and water absorption kinetics of three varieties of Mucuna beans, Scientific Reports 11, 2021, p.5450. https://doi.org/10.1038/s41598-021-85087-8 .

23. **E. A. Baryeh,** " Physical properties of bambara groundnuts", J. Food Eng. 47(4), 2001, pp. 321–326.

24. **M. Awad & A. Al-Humaidhi**, " Engineering methods for measuring the physical and mechanical properties", water content, and flow rates of underground rocks containing water, the first symposium for rationalizing water consumption and developing its sources, Riyadh, Saudi Arabia(1421 AH).

25. **E. P. Kearsley and P. J. Wainwright**, " Porosity and permeability of foamed concrete" ,‖ Cement and Concrete Research,. vol. 31, no. 5, 2001, pp. 805-812.

26. **R. Shabbar, P. Nedwell, and Z. Wu**, " Porosity and Water Absorption of Aerated Concrete with Varying Aluminium Powder Content", International Journal of Engineering and Technology, Vol. 10, No. 3, 2018, PP.234-238. DOI: 10.7763/IJET.2018.V10.1065.