

Bamboo lumber – an innovative sustainable raw material and an accelerated weathering study for establishing its durability

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Abstract: Bamboo lumber was prepared using *Bambusa bamboos* species and its weathering performance was evaluated under natural and accelerated weathering. Specimens of bamboo lumber were exposed to natural weathering for 150 days. Another set of specimens were exposed to UV light source (UVA 360) in accelerated weathering tester up to 250 hours. A comparative study on the level of degradation in natural and accelerated weathering was made by evaluating CIEL*a*b* colour changes measured using a Hunter lab spectro-colorimeter. Rate of color change due to photo-degradation were evaluated. Results showed that all three color axes, viz. lightness (L*), redness (a*) and yellowness (b*) changed linearly with respect to time under natural exposure, but only L* was changed under accelerated weathering, keeping a* and b* values to be almost constant. Photodegradation of bamboo was mainly due to UV light absorption by chromophores present in the lignin, which constitutes about 32.2 % of total bamboo.

Keywords: *Bambusa bamboos*, CIELAB color system, photodegradation, spectro-colorimeter, chromophores, sustainable raw material, durability, bamboo lumber

Introduction

Bamboo is sustainable raw material commonly used as a substitute building material in tropical and sub-

tropical regions of the world because of its fast growth rate, high mechanical strength, short rotation age, easy machinability (Escamilla *et al.*, 2019). The application of bamboo composite in exterior environments has been greatly limited due to its durability against weathering. Weathering is the general term, used to define the slow degradation of materials when exposed to weather. Weathering of a material is the change in its physical, chemical, aesthetic, compositional or molecular structure, when it is subjected in the external parameters such as temperature, pH value etc. of the environment (Temiz, 2005; Miklečić and Jirous-Rajković, 2011; Beg and Pickering 2008; Kim *et al.*, 2008; Baysal *et al.*, 2016; Azwa *et al.*, 2013; Feist and Williams, 1991).

This degradation mechanism depends on the type of material; but the cause is a combination of factors such as moisture, sunlight, heat/cold, chemicals, abrasion by windblown materials and biological agents. There are many potential indoor and outdoor applications in which the bamboo composites can be used. For example, bamboo lumber/bamboo laminate composites can be used for outdoor and indoor flooring, wooden plank road, container flooring, garden landscaping, wind turbine blade, furniture etc.

Feist and Hon (1984) studied the chemistry of weathering and protection and found that UV light interacts with lignin to initiate discoloration and deterioration. Sahin and George (2011) noted that the color changes in wood surfaces of European pine, fir, Bosnian pine, chestnut and cherry had been modified by a new nano particulate treatment. They showed that anti-UV treatment of wood was effective

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in discoloration of wood. They were obscure with the reason for wood discoloration; however, they reported that this could be due to the chemical modification, which would not itself affect all of the color properties of wood.

Yu *et al.*, 2014 studied the method of producing bamboo fiber reinforced composite (BFRC) with high yield and investigated the mechanical properties of BFRC comparing with those of commercial bamboo scrimber (BS) and laminated bamboo lumber (LBL). It has been found that the wood composites made of bamboo are also prone to weathering. Failure to recognize the effects of weathering can lead to catastrophic failure of wood and bamboo composites.

Rosu *et al.*, (2010) investigated the reason for wood discoloration using FTIR and CIELAB techniques. They investigated the effect of UV-visible light irradiation on the changes in the color and chemical composition of the surfaces of non-modified and chemically modified *Abies alba* L. (fir, a softwood). Their result found that the decrease in photo-degradation of chemically modified wood might be due to the light stability of lignin to the polychromatic light action.

Okubo *et al.*, (2004) reported the development of composites for ecological purposes (Eco-composites) using bamboo fibers and their basic mechanical properties. The tensile strength and modulus of PP based composites using steam-exploded fibers found to be increased about 15 and 30 %, due to well impregnation and the reduction of the number of voids.

Chawla *et al.*, (2016) investigated the production of an engineered bamboo lumber product. The properties (physical and mechanical) were evaluated as per IS: 1734 (1983) and found that Bamboo Strand Lumber can be used as an alternative to timber for different application. Nagarajappa and Pandey (2016) included the process of modification of wood using isopropenyl acetate (IPA) in the presence of anhydrous aluminum chloride as a catalyst. They found suppressing photo-yellowing and UV degradation of wood polymers along with good hygroscopicity and dimensional stability.

Patil and Talekar (2017) studied the composite material, their applications and market trend. They found that, from the last thirty to thirty-five years composite

materials, plastics and ceramics have been the dominant emerging materials. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications.

Li *et al.*, (2018) evaluated the influence of media treatments on color changes, dimensional stability, and cracking behavior of bamboo scrimber. The results showed that the bamboo scrimber specimens became darker after all treatment conditions, especially the oil treatments and infrared drying. The color of the oil-treated bamboo scrimbers was found to be more homogenous than the others.

Outdoor bamboo scrimber with or without this coating was investigated under accelerated weathering. The results found that the colour, glossiness, CA, SFE, and functional groups photostability of the sample with the UV shielding coating increased significantly compared to those of the control sample (Li *et al.*, 2019).

Topaloglu (2019) studied the effect of accelerated weathering on density, compression strength parallel to grain, static modulus of rupture and modulus of elasticity of untreated and waterborne-treated bamboo. Amine copper quat-1900 (ACQ) treatment generally provided the best protection against weathering in all mechanical tests for both bamboo and wood specimens, while wolmanit-CB (CCB) treatment provided an effective protection against weathering in compression strength for Oriental beech. Boric acid-borax (BB) treatment provided the least protection against weathering for bamboo and wood specimens compared to other waterborne preservatives.

Several bamboo-based materials such as bamboo plywood, particle board, bamboo-laminated strand board, bamboo scrimber etc. have been developed (Matsumoto *et al.*, 2001; Nugroho and Ando, 2001; Qin *et al.*, 2012; Chaowana, 2013). The process of manufacturing these products has been successfully developed in Asia. Bamboo is excellent natural composite material; but poor in durability and requires special coating to enhance the life in exterior condition. Bamboo and their composites can be protected against weathering, and the preservative and finishing treatments can improve its durability like wood (Asif, 2009; Williams, 2005; Liu *et al.*, 1994; Hung *et al.*, 2012; Zhou and Huang 2016).

Yu *et al.*, 2021 investigated the discoloration and degradation of Bamboo under Ultraviolet Radiatio. Different types of bamboo samples commonly used in the industry were studied experimentally under two types of ultraviolet (UV) light. Effects of light sources, radiation time, and distances on discoloration and discoloration mechanism were systematically studied. The color change of bamboo scrimber under UV radiation was less and slower than that of untreated bamboo due to high density and heat treatment, and the dark carbonized scrimber changed less than that of the light carbonized scrimber.

Weathering study helps to predict the life of bamboo lumber, when it is exposed to natural weather under different radiation of electromagnetic spectrum. The main objective of accelerated study on bamboo lumber is to determine its photodegradation property (in outdoor weathering and through Xenon weatherometer)

according to American Standard ASTM G154-06 (2006).

Materials and methods

Bambusa bambos species of bamboo and phenol formaldehyde resin were used to prepare bamboo lumber.

Preparation of Bamboo Lumber: Bamboo lumbers were prepared using the procedure described below.

Cross Cutting: A raw bamboo culm is cut for the 4'6" length, transverse to the bamboo fibers with the help of cross cutting Machine (Fig. 1). After cross cutting, the culm is now ready for primary processing and conversion into splits and slivers.

Outer Nodes Removal: After cross cutting of the bamboo, the outer nodes (protrusions) are removed in order to have a smooth surface over the culm by external knot removing machine (Fig. 2).



Fig 1. Cross cutting machine



Fig 2. External Knot removing machine



Fig 3. Bamboo splitting machine



Fig 4. Width sizing and internal Knot removing machine



Fig 5. Grove making machines



Fig 6. Hydraulic hot press with side pressure



Fig 7. Bamboo Limber

Bamboo Splitting: Splitting process involves the splitting of bamboo culm of desired width through radial-bladed circular splitter which contains 4 or 6 or 8 blades (Fig. 3), using a mallet over the vertically positioned bamboo section

Inner Nodes Removal: After the splitting of bamboo, the nodes and other protrusions are seen in the split pieces. The knots are simply the internal projections of the node. In most cases, the knot would need to be removed for smoother surface for further processes. Knot has been removed by Knot removing machine (Fig. 4).

Bamboo Sliver/Slat Making: Split bamboos, whose internal knots and outer protrusions are removed, are slivered or made into slats, depending on the required thickness. The objective of slivering is to remove

the outer and inner layers of bamboo, due to their low adhesion property.

Grooving and Sampling: All the slivered pieces of bamboo are grooved using a grooving machine (Fig. 5). The objective of grooving is to have the penetration of the resin inside the strips, which can provide more strength to bamboo products. Each slivered pieces of bamboo are then cut into a desired length (generally 12 or 13 inches) and this process is called as “Sampling”.

Resin Application: Conventional Phenol Formaldehyde resin is poured in a container and the same amount of water (1:1) is added to reduce its viscosity. Boiled bamboo split samples are now dipped separately into this Phenol Formaldehyde resin for about 8 minutes.

Air Drying: Resin-dipped crushed bamboo strips are kept in atmospheric condition for air drying by placing the strips vertically with support in a container for 3-4 hours to drain out excess resin from strips. After air drying, strips are kept in an industrial oven at 50 °C - 60 °C until the moisture content of strips reach 10-12 %. But oven drying of the strips can lead to poor adhesion of the bamboo lumber. Therefore, these strips can also be dried at the atmospheric conditions for 24-48 hours.

Assembling and Hot Pressing: In this process, resin-dipped crushed strips are stacked in such a way that all crushed strips are aligned in same direction. Then assembly was loaded in a hydraulic hot press (Fig. 6), whose temperature is maintained at 145 ± 5 °C, with the Gauge Pressure of 120-130 kg/cm² and Specific Pressure

of 40-45 kg/cm² for 15 minutes. Hence the obtained product is a “Bamboo Lumber” (Fig. 7). This product is supposed to be placed under a heavy load unless it cools down, to avoid any deformation and is trimmed to a required size for the testing of its mechanical properties.

Evaluation of photo-degradation of bamboo lumber

Three samples were made from each lumber, meant for (a) no-exposure, (b) outdoor weathering condition [60 days and 150 days] with (dimensions 150×30×10 mm³) and (c) accelerated weathering (dimensions 150 × 40 × 4 mm³) under UV light for 250 hours, respectively. UV rays were incident normal to the surface of the samples, so as to increase the cross-sectional area of radiation absorption. Color changes

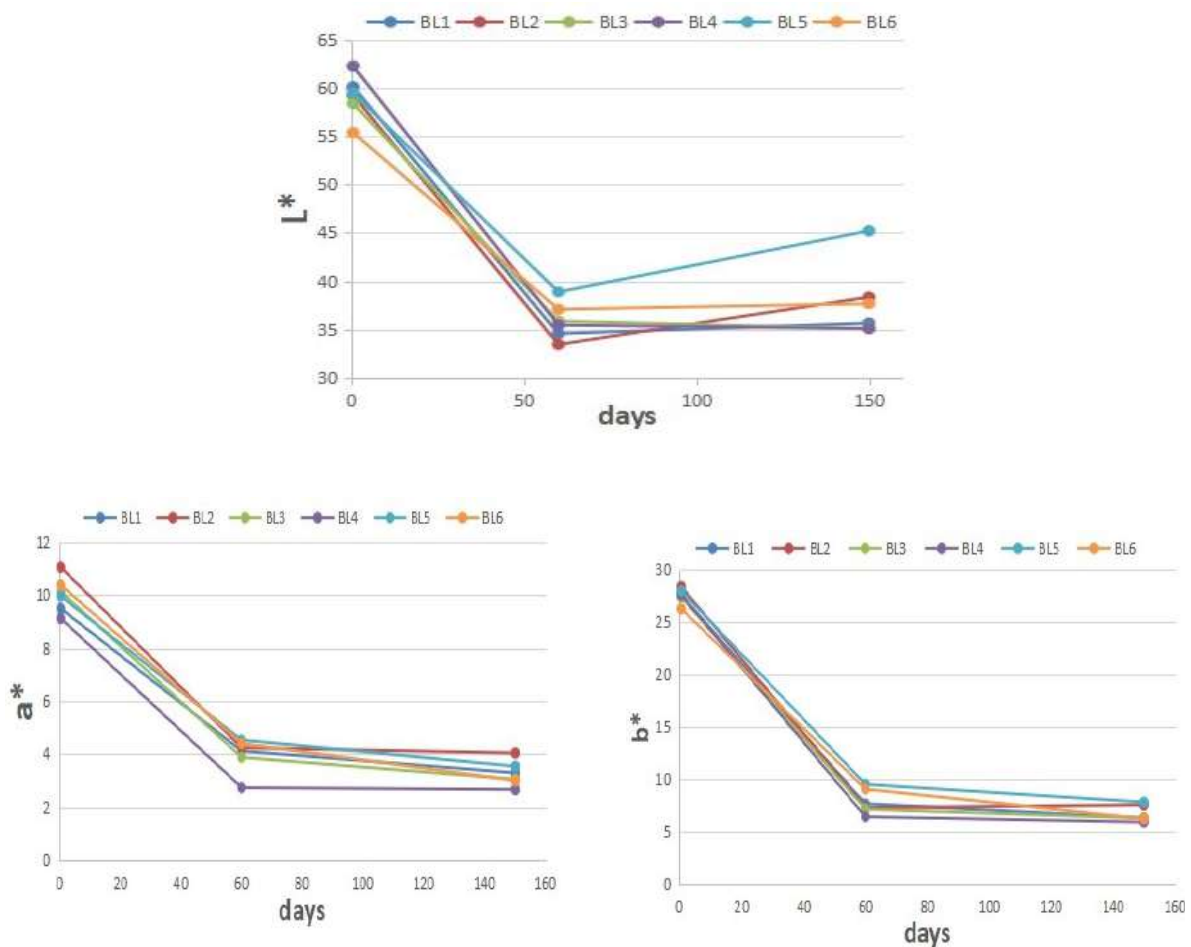


Fig 8. Color change values of bamboo lumber due to natural weathering. (a) L*, (b) a*, (c) b*

in unexposed (freshly prepared) bamboo lumber was recorded through CIEL*a*b* technique in a Hunter lab Spectrocolorimeter, where the lightness (L^*), redness (a^*) and yellowness (b^*) coordinates were measured for each sample, at different positions. A shift in color toward red signifies Δa^* positive while the shift in color from blue toward yellow signifies Δb^* positive. Similar set of values were recorded after 60 days and 150 days of lumber exposure in outdoor or natural condition. Third sample of lumber was kept in a weatherometer (Qlab QUV accelerated weathering tester) under UV rays exposure for a period of 250 hours, at the chamber temperature maintained at 60 °C and the CIEL*a*b* readings were recorded. Considering $\Delta E1$ and $\Delta E2$ to be the color difference values of before exposure to 150 days outdoor and before exposure to weatherometer respectively, $\Delta E1$ and $\Delta E2$ can be calculated using the formula:

$$\Delta E = [(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad \text{----- (Eq. 1)}$$

Results and discussions

Samples of Bamboo lumber were subjected to natural weathering and exposed to UV light source in an accelerated weathering tester or chamber and the extent of discoloration due to exposure were monitored using a Spectro colorimeter.

Natural outdoor weathering

Fig. 8 (a), (b) and (c) describe the lightness, redness and yellowness value, respectively before exposure and followed by the exposure of 60 and 120 days.

All three figures show that there was drastic decrease in L^* , a^* and b^* values from initial day to 60th day and then their L^* , a^* and b^* values attain constancy. Most of the changes were observed during first few days.

CIE $L^*a^*b^*$ values were recorded for unexposed bamboo lumber samples and for those samples which were exposed to Xenon fluorescent UV light under weatherometer for 250 hours. Drastic color difference (ΔE) was observed (Fig 9). Which is due to the high intensity of UV light, emitted from Xenon lamp, and this can affect chromophores located on lignin.

Table 1 describes the changes in color difference values due to natural and accelerated weathering, which show the significant change in color with time under both the conditions. Table 2 describes the individual change in L^* , a^* and b^* values under natural and accelerated weathering with reference to unexposed samples. All three values of L^* , a^* and b^* for naturally exposed samples decreased with time, which means that the samples became lighter and attained reddish-yellow color. Accelerated (UV) exposed samples also became lighter, but their Δa^* showed negative, which means that they tend to attain blue color; and Δb^* value remained unaffected. Table-3 compares the slope values of natural weathering, exposed in sunlight and accelerated weathering, exposed in UV lamp. It can be clearly seen that slope value of ΔE per day under accelerated condition is 1,17 while that of natural condition is 0,20 per day,

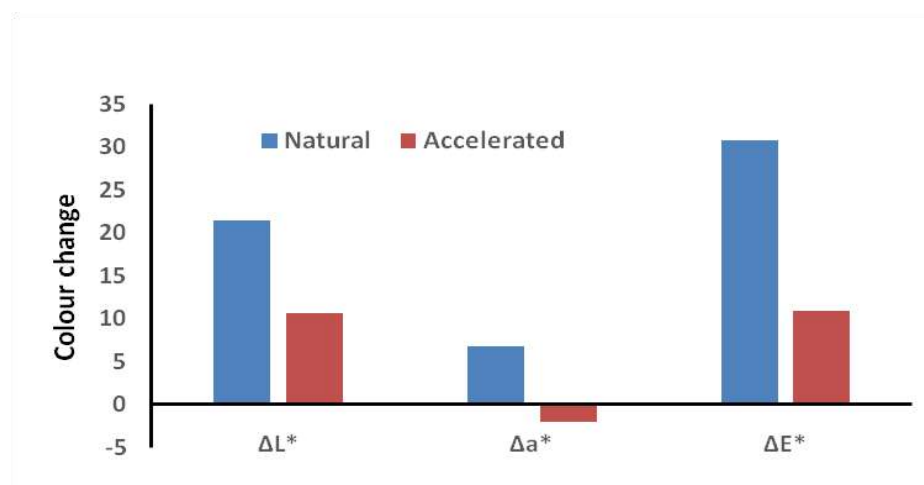


Fig 9. Comparison of colour change in natural and accelerated weathering of bamboo lumber

Table 1. Change in color difference values [natural (150 days) and accelerated weathering (250 hours)]

Sample	Natural weathering (ΔE_{sun})	Accelerated weathering (ΔE_{uv})
BL1	33,04	14,77
BL2	30,36	12,81
BL3	32,26	9,63
BL4	35,41	13,55
BL5	25,52	10,18
BL6	27,76	4,73

BL1-BL6= BL represent code for developed bamboo lumber while 1---6 are number of samples

which means that the bamboo lumber is sensitive to UV radiation. Careful observation shows that the lightness values had decreased with time, keeping the redness and yellowness value almost same as they were in unexposed samples as shown in table 2. Chemical composition of bamboo asserts that it contains lignin as a binding material, which is responsible for its color degradation through chromophore action.

Air-dried six samples of each were taken for testing. MoE of the samples was determined from the resonance frequency of longitudinal and flexural vibrations method. MOE was measured by Flexural vibration method which is given by standard formula (Chauhan and Sethy, 2016).

$$\text{MOE} = \frac{0.946 \rho f^2 t^3}{D^3} \dots\dots\dots (\text{Eq. 2})$$

Where: L = length of sample (cm); F = frequency of flexural vibration (unit less); ρ = density of bamboo lumber sample (grams/cm^3); D = Thickness of bamboo lumber sample.

As expected the density decreases after accelerated weathering and it further decreases for natural weathering compared to the control sample. Also, the modulus of elasticity density decreases after accelerated weathering and it further decreases for natural weathering compared to the control sample. density was found to have a strong positive association with modulus of elasticity.

Table 2. Variation of L*, a* and b* values under accelerated weathering with time

Samples	Natural weathering			Accelerated weathering		
	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
BL1	24,53	6,19	21,25	14,52	-2,67	0,49
BL2	20,95	6,99	20,84	12,71	-0,54	1,53
BL3	23,36	7,07	21,09	9,34	-2,17	-0,85
BL4	27,25	6,44	21,68	13,16	-3,13	0,80
BL5	14,29	6,41	20,15	9,74	-2,90	-0,64
BL6	17,75	7,36	20,03	4,53	-0,80	-1,12

Where L*- lightness, a*- redness and b*- yellowness

Table 3: Comparison of slope ($\Delta E/\text{day}$) values of natural and accelerated weathering

Natural weathering (ΔE_{sun}) avg.	Slope ($\Delta E_{\text{sun}}/\text{day}$)	Accelerated weathering (ΔE_{uv}) avg.	Slope ($\Delta E_{\text{uv}}/\text{day}$)
30,72	0,20	12,19	1,17

Table 4: Comparison of mechanical values of natural and accelerated weathering with Control sample

Test	Control sample	Accelerated Weathering	Natural Weathering
DENSITY, grams/cm ³	1,12	1,09	1,04
MoE, GPa	20,51	19,26	16,39

Conclusions

Bamboo lumbers were prepared and extent of color change under natural and accelerated weathering conditions was evaluated. The amount of sunlight, as perceived in the atmosphere contains low intensity of ultra-violet radiation, due to which the colour difference rate was found to be 0,20 per day. Another set of similar samples of bamboo lumber were exposed to UV lamp in an accelerated weathering tester and the rate of color difference was recorded as 1,17 per day. The colour changes is attributed to the chromophores present in lignin which is 32,2 % of the total chemical composition of bamboo. All three-color axes changed in accordance with time under natural exposure, but only L* decreased with time under accelerated UV exposure, keeping their* and b* values unaffected.

References

- Asif, M. 2009. Sustainability of timber, wood and bamboo in construction. *Sustainability of Construction Materials*. Woodhead Publishing Ltd., Cambridge, UK, 31-54P. DOI: 10.1533/9781845695842.31.
- American Society for Testing and Materials. 2006. ASTM G154-06: Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Non-metallic Materials. West Conshohocken, PA, USA. <https://www.astm.org/DATABASE.CART/HISTORICAL/g0154-06.htm>
- Azwa, Z.N., Yousif, B.F., Manalo, A.C. and Karunasena, W. 2013. A review on the degradability of polymeric composites based on natural fibres. *Mater. Des.* 47: 424-442. <https://doi.org/10.1016/j.matdes.2012.11.025>.
- Baysal, E., Tomak, E.D., Topaloglu, E. and Pesman, E. 2016. Surface properties of bamboo and Scots pine impregnated with boron and copper-based wood preservatives after accelerated weathering. *Maderas-Cienc Tecnol.* 18 (2): 253-264. <http://dx.doi.org/10.4067/S0718-221X2016005000023>.
- Beg, M.D.H. and Pickering, K.L. 2008. Accelerated weathering of unbleached and bleached kraft wood fibre reinforced polypropylene composites. *Polym Degra & Stab* 93 (10):1939-1946. <https://doi.org/10.1016/j.polymdegradstab.2008.06.012>.
- Chawla, V.K., Kushwaha, P.K., Nandanwar, A., Prakash, V. and Mohanty, B.N. 2016. Development of bamboo strand lumber for housing application. IPIRTI Research Report: 194.
- Chaowana, P. 2013. Bamboo: An alternative raw material for wood and wood-based composites. *J. Materials Sci. Res.* 2 (2): 90-102. <https://doi.org/10.5539/JMSR.V2N2P90>.
- Escamilla, Z.E., Archilla, H., Nuramo, D.A. and Trujillo, D. 2019. Bamboo: An Engineered Alternative for Buildings in the Global South. *Bioclimatic Architecture in Warm Climates*, Springer: 397-414. https://doi.org/10.1007/978-3-030-12036-8_15.
- Feist, W.C. and Hon, D.N.S. 1984. Chemistry and weathering protection. In: Rowell, Roger M., ed. *The Chemistry of solid wood*. Advances in Chemistry Series 207. Washington, DC: American Chemical Society; 1984: Chapter 11.
- Feist, W.C. and Williams, R.S. 1991. Weathering durability of chromium-treated southern pine. *Forest Prod. J.* 41 (1): 8-14. <https://agris.fao.org/agris-search/search.do?recordID=US9323581>.

- Hung, K.C., Chen, Y.L. and Wu, J.H. 2012. Natural weathering properties of acetylated bamboo plastic composites. *Polym. Degrad. & Stabil.* 97(9):1680-1685. <http://x.doi.org/10.1016/.polymdegradstab.2012.06.016>.
- Kim, J.S., Lee, K.H., Cha, M.Y. and Kim, Y.S. 2008. Anatomical, physical and chemical changes of bamboo (*Phyllostachys pubescence*) during weathering processes. International Research Group on Wood Preservation, IRG/WP 08-10650.
- Li, J., Chen, Y., Xu, J., Ren, D., Yu, H., Guo, F. and Wu, Z. 2018. The Influence of Media Treatments on Color Changes, Dimensional Stability, and Cracking Behaviour of Bamboo Scrimber. *Intern. J. Polymer Sci.* 2018:1-7. <https://doi.org/10.1155/2018/6068589>.
- Li, N., Bao, M., Rao, F., Shu, Y., Huang, C., Huang, Z., Chen, Y., Bao, Y., Guo, R. and Xiu, C. 2019. Improvement of surface photostability of bamboo scrimber by application of organic UV absorber coatings. *J. Wood Sci.* 65:7. <https://doi.org/10.1186/s10086-019-1789-1>.
- Liu, R., Ruddick, J.N.R. and Jin, L. 1994. The influence of copper (II) chemicals on the weathering of treated wood. Part I. ACQ treatment of wood on its weathering. International Research Group on Wood Preservation, IRG/ WP 94-30040.
- Matsumoto, K., Yamauchi, H., Yamada, M., Taki, K. and Yoshida, Y. 2001. Manufacture and properties of fiberboard made from Moso Bamboo. *J. Japan Wood Res. Soci. (Japan)* 47(2): 111-119.
- Miklečić, J. and Jirouš-Rajković, V. 2011. Accelerated weathering of coated and uncoated beech wood modified with citric acid. *Drvna Industrija* 62 (4): 277-282. <https://doi.org/10.5552/drind.2011.1116>.
- Nagarajappa, G.B. and Pandey, K.K. 2016. UV resistance and dimensional stability of wood modified with isopropenyl acetate. *J. Photochemistry & Photobio. B: Biol.* 155: 20-27. <https://doi.org/10.1016/j.jphotobiol.2015.12.012>.
- Nugroho, N. and Ando, N. 2001. Development of structural composite products made from bamboo II: fundamental properties of laminated bamboo lumber. *J. Wood Sci.* 47(3): 237-242. <https://doi.org/10.1007/BF01171228>.
- Okubo, K., Fujii, T. and Yamamoto, Y. 2004. Development of bamboo-based polymer composites and their mechanical properties. *Composites Part A: Applied Sci. & Manufact.* 35(3): 377-383. <https://doi.org/10.1016/j.compositesa.2003.09.017>.
- Patil, A. and Talekar, V. 2017. A Review on Bamboo Fiber Composites. *Iconic. Resea. & Engg. J.* 1(2):54-72. <http://irejournals.com/formatedpaper/1700041.pdf>.
- Qin, L., Wen-ji, Y. and Yu, Y.L. 2012. Research on properties of reconstituted bamboo lumber made by thermo-treated bamboo bundle curtains. *Forest Prod. J.* 62(7): 545-550. <https://doi.org/10.13073/FPJ-D-12-00058.1>
- Rosu, D., Teaca, C.A., Bodirlau, R. and Rosu, L. 2010. FTIR and color change of the modified wood as a result of artificial light irradiation. *J. Photoche. & Photobio. B: Biol.* 99(3): 144-149. <http://dx.doi.org/10.1016/j.jphotobiol.2010.03.010>.
- Sahin, H.T. and George, I.M. 2011. Colour changes in wood surfaces modified by a nanoparticulate based treatment. *Wood Resea. J.* 56(4): 525-532. <http://www.woodresearch.sk/wr/201104/08.pdf>.
- Chauhan, S. and Sethy, A. 2016. Differences in dynamic modulus of elasticity determined by three vibration methods and their relationship with static modulus of elasticity. *Maderas, Cienc. tecnol.* 18 (2): 373-382. <http://dx.doi.org/10.4067/S0718-221X2016005000034>.
- Temiz, A. 2005. The effect of simulated weathering on preservative treated wood. PhD Thesis. Karadeniz Technical University, Trabzon, Turkey.
- Topaloglu, E. 2019. Effect of Accelerated Weathering Test on Selected Properties of Bamboo, Scots Pine and Oriental Beech Wood Treated with Waterborne Preservatives. *Drvna Industrija* 70 (4): 391-398. <http://dx.doi.org/10.5552/drvind.2019.1855>.
- Williams, R.S. 2005. Weathering of wood. *Handbook of wood chemistry and wood composites*. Boca Raton: CRC Press, Ch-7: 139-185.
- Yu, Y.L., Huang, X. and Yu, W. 2014. A novel process to improve yield and mechanical performance of bamboo fiber reinforced composite via mechanical treatments. *Composites Part B Engg.* 56: 48-53. <https://doi.org/10.1016/J.COMPOSITESB.2013.08.007>.
- Yu, H., He, S., Zhang, W., Zhan, M., Zhuang, X., Wang, J. and Yu, W. 2021. Discoloration and degradation of bamboo under ultraviolet radiation. *Inter. J. Polym. Sci.* 2021, Article ID 6803100, 10 pages <https://doi.org/10.1155/2021/6803100>.
- Zhou, X. and Huang, S. 2016. Effect of antiaging agents on the outdoor natural weathering of bamboo powder/polypropylene foamed composites. *J. Vinyl. Addit. Technol.* 22: 311-319. <https://doi.org/10.1002/vnl.21433>.