Discolouration and strength reduction of *Bambusa vulgaris* after the weathering process

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**Abstract.** *Bambusa vulgaris* Schrad was studied for its colour and strength before and after weathering process. Bamboo splits of 300 mm (length) x 20 mm (width) x original thickness were conditioned in a conditioning room at 20±2°C and 65±2% relative humidity before and after weathering for 3, 6, and 9 weeks. A Minolta colour reader and a Munsell soil colour chart were used to assess the colour changes (\(\Delta E\)) and whitish value (W) of bamboo splits before and after the weathering process. Using Universal Testing Machine, the strength of weathered bamboo splits was tested. Results show the colour of bamboo splits changed dramatically (8% to 21%) over time, whereas the whitish value (W) of the bamboo splits reduced 8% to 31% after 3 to 9 weeks of exposure. Bamboo density was reduced by 3% to 17%. Modulus of Elasticity and Modulus of Rupture, in terms of strength qualities, were greatly reduced (20 MPa to 24 MPa) and (12 MPa to 16 MPa), respectively. After being exposed to the weather for 3, 6, and 9 weeks, the colour of *Bambusa vulgaris* changed substantially, and the density and strength of bamboo decreased.

**Keywords:** Colour changes; whitish value; density; Modulus of Rupture; Modulus of Elasticity.

1. Introduction

Bamboo is among one of the fastest-growing grasses which only takes a few months (about 2 inches per hour) to mature and can be used at the age of 4 years compared to wood which takes more than ten years to mature and be usable [1]. Bamboo has been used for countless centuries as indoor and outdoor building furniture as well-known by many people in the world. This material has multiple uses which can be converted into other products such as paper, various construction materials like bamboo-reinforced concrete [2], bamboo flooring and laminate [3], ply bamboo [4] and scaffolding [5]. Bamboo also can be converted into composite products, such as particleboard [6], oriented strand board [7], medium density fibreboard [8], bamboo fibre reinforced cement composites [9], bamboo thermoplastic composites [10] and others.

Bamboo, like wood, is degradable when exposed to weathering. Weathering is a chemical and physical process that alters the appearance of bamboo. The duration of the weathering process is linked to chemical changes, lignin degradation and carboxyl synthesis, all of which cause colour variations in bamboo [11]. Meanwhile, the density is significant since it is directly related to the strength properties of bamboo, influencing its use in a variety of applications [12].
To enhance the service life of bamboo or bamboo products, understanding the weathering process and the development of suitable treatments to retard this degradation is very crucial. Failure to recognize the effects of weathering can lead to catastrophic failure of bamboo products and other products used with bamboo. The durability of this material should be taken into consideration and evaluated to know the suitability of bamboo for indoor or outdoor utilization. *Bambusa vulgaris* Schrad in the local name known as “Buluh minyak” was used in this study. The study was undertaken to evaluate the colour and strength properties of bamboo (*Bambusa vulgaris*) when exposed to outdoor weathering conditions.

2. Material and methods

2.1 Study site
This experiment was conducted at University Malaysia Sabah. Bamboo splits (*Bambusa vulgaris*) were exposed to weathering on the rooftop for 3, 6, and 9 weeks because of the spacious area and had maximum exposure to sun and rainfall.

2.2 Preparation of bamboo samples
The sample used in this study was *Bambusa vulgaris* Schrad, which was taken from Kawang Forest Reserve, Papar, Sabah, Malaysia. The culms were cut and splits into 300 mm (length) x 20 mm (width) x original thickness of the culm wall. All bamboo splits were conditioned in a conditioning room at 20±2°C and 65±2% relative humidity until constant weight. The weight of the bamboo splits was measured, and the initial colour was recorded at the middle of the bamboo surfaces. The bamboo splits were arranged on special-built racks with a slope of 45° (Figure 1) to avoid draping water during rainy days and to get maximum exposure to sunlight and rainfall. The bamboo splits were left exposed to the weather for 3, 6 and 9 weeks prior to colour and strength evaluation. Unexposed bamboo splits were used for control.

![Figure 1](image-url). Racks used for weathering test.

2.3 Colour evaluation (Whitish Index)
For colour evaluation, Minolta Colour reader CR10 was used (Figure 2a). The colour after exposure was read at the same place where initial reading was made. Colour evaluation of the surface of the splits bamboo was carried out using a fixed colour system L* a* and b* [13]. From black to white, L represents the brightest value (Figure 2b). Whiter bamboo is indicated by a higher L value. The colour transition from green to red is represented by a value of ‘a’. The bamboo is redder if the ‘positive value of a’ is higher. The colour of the bamboo is greener if ‘the negative value...
of a’ is higher. A colour transition from yellow to blue is indicated by the value of b. A higher ‘positive value of b’ implies that the bamboo is yellower, whereas a higher negative value suggests that the bamboo is bluer. The colour changes (ΔE) and whitish value (W) of the bamboo were calculated using the following equations (1) and (2).

\[
\Delta E = \left( (\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2}
\]

\[
W = 100 - \left( (100 - L^*)^2 + a^2 + b^2 \right)^{1/2}
\]

where,  
- \( L^* \) = Fairest value (The higher the value, it become more white)  
- \( a^* \) = ‘Chromaticness index’ (The higher the value, it become redder)  
- \( b^* \) = ‘Chromaticness index’ (The higher the value, it become more yellow)  
- (ΔE) = Colour changes the value  
- W = Whitish value

Munsel Soil Colour Chart was also used to determine the colour before and after weathering for the bamboo splits.

2.4 Determination of density
After the static bending test, a 20-mm piece was cut near the failure of the test specimen. The volume of each sample was determined. The samples were weighed to the nearest 0.01 g. The samples were then dried in an oven at 103 ± 2°C until constant weight. Oven-dry weights were recorded and determined for their density using equation (3).

\[
\rho = \frac{W_0}{V} \]  

where,  
- \( W_0 \) = Oven-dried weight, kg  
- \( V \) = Volume, m³

2.5 Static bending test
The static bending tests were performed according to Bureau of Indian Standard IS 8242, 1976 [14]. Before the samples were tested, they were again conditioned at 20°C and 65% relative humidity until weight remain constant (EMC at 12%). Static bending test was conducted after the colour of the bamboo
splits was taken. Specimens of 300 mm (length) x 20 mm (width) x original thickness of the culm wall bamboo splits were used for testing using an Instron 1195 Universal Testing Machine attached to a computer in a testing room with controlled temperature of 20 ± 2°C and 65 ± 3% relative humidity. The series of strength property were evaluated using equations (4) and (5):

\[
\text{Modulus of Rupture, } \text{MOR} = \frac{3 P' L}{2 b h^2} \tag{4}
\]

\[
\text{Modulus of Elasticity, } \text{MOE} = \frac{P L^3}{4 b h^3 d} \tag{5}
\]

where,
- \(P\) = Load at proportional limit, N,
- \(b\) = Width of specimen, mm,
- \(h\) = Depth of specimen, mm,
- \(L\) = Span, 210 mm,
- \(P'\) = Maximum load in N,
- \(d\) = Deflection at proportional limit, mm.

2.6 Statistical analysis

All data were statistically analysed using one-way analysis of variance (ANOVA) and the mean value of each property was separated using Least Significant Difference (LSD) test to determine the differences between treatment levels. The analysis was carried out using the Statistical Package for the Social Sciences (SPSS) software.

3. Results and discussion

3.1 Discolouration of bamboo

Table 1 shows the mean colour changes (\(\Delta E\)) and whitish value (W) of \textit{Bambusa vulgaris} after exposure to weather for 3 (E3W), 6 (E6W) and 9 (E9W) weeks compared to control (UE) samples.

Table 1. Mean colour changes (\(\Delta E\)) and whitish value (W) of \textit{Bambusa vulgaris} split before and after weathering.

| Exposure duration (weeks) | N\(^3\) | \(\Delta E\) | Munsell colour | W (%) |
|---------------------------|--------|-------------|----------------|-------|
| UE                        | 16     | 0.00 \(^a\) (0.00) | Pale Yellow | 59.37 \(^a\) (2.72) \(^2\) \{0\} |
| E3W                       | 16     | 7.91 \(^a\) (4.39)  | Light yellowish-brown | 54.64 \(^b\) (1.74) \{-7.96\} \(^4\) |
| E6W                       | 16     | 17.17 \(^b\) (6.45) | Light yellowish-grey | 43.76 \(^c\) (6.92) \{-26.29\} |
| E9W                       | 16     | 21.04 \(^b\) (7.32) | Very dark grey | 41.26 \(^c\) (7.55) \{-30.50\} |

Note: \(^1\) Means followed with the same letter are not significantly different (p<0.05)  
\(^2\) Values in parentheses are standard deviations  
\(^3\) N = number of samples  
\(^4\) \{ \} = % change from control

Results found that the colour of \textit{Bambusa vulgaris} change about 8 to 21% after exposure to weather for 3 to 9 weeks. After 3 weeks of exposure, there was no significant difference at p<0.05 of colour change (7.91%) but after 6 to 9 weeks of exposure, there were considerable colour shifts (about 17.17 to 21.04%). This clearly indicates that the longer the exposure period, the greater the colour change. When determined using Munsel Soil chart, \textit{B. vulgaris} show a colour change from pale yellow (control) to light yellowish brown after exposure for 3 weeks. The colour continues to change to light yellowish-grey and very dark grey after 6 and 9 weeks, respectively. The changes in bamboo colour are considered a superficial phenomenon because of the small penetration of ultraviolet and visible light into bamboo and its initiation of photochemical reactions and their effect on the bamboo colour [15].

The results also found that there was a significant difference in the whitish value of \textit{B. vulgaris} samples after exposure from 3 to 9 weeks compared to unexposed samples. A decrease in the whitish value indicates that the colour of the bamboo becomes darker. UV also alters the structure of lignin at the surface, which in turn leads to degradation of brightness and reflectance of red-green and yellow-
blue spectra and erosion of the degraded surface [16]. Table 1 also shows the whitish value of *B. vulgaris* calculated against control. The values exhibit that the whitish value reduction of *B. vulgaris* increases with the increment of exposure duration. The decrease in the whitish value of bamboo probably be caused by photodegradation by ultraviolet light and affected by moulds and blue stain infestation [17].

3.2 Evaluation of density and strength properties of bamboo

Table 2 summarizes the results of density and strength properties of weathered and unweathered splits *Bambusa vulgaris*.

### Table 2. Mean density and strength properties of exposed and unexposed *B. vulgaris* splits after weathering process.

| Exposure period (weeks) | N  | Density (kg/m$^3$) | MOE (MPa) (x10$^3$) | MOR (MPa) |
|-------------------------|----|--------------------|----------------------|----------|
| UE                      | 16 | 611 $^a$ (0.14)$^2$ | 10.96 $^a$ (4.96)$^2$ | 129 $^a$ (0.03) |
| E3W                     | 16 | 639 $^a$ (0.12) {3.39}$^4$ | 8.80 $^b$ (2.44) {-19.70} | 113 $^b$ (0.02) {-12.40} |
| E6W                     | 16 | 497 $^b$ (0.09) {-18.41} | 8.30 $^b$ (2.62) {-24.27} | 108 $^b$ (0.03) {-16.27} |
| E9W                     | 16 | 511 $^b$ (0.07) {-17.44} | 8.31 $^b$ (2.08) {-24.17} | 111 $^b$ (0.02) {-13.95} |

Note:  
1. Means followed with the same letter are not significantly different (p<0.05)  
2. Values in parentheses are standard deviations  
3. N = number of samples  
4. $\{\} =$ % change from control

The results indicated that the density, modulus of elasticity (MOE) and modulus of rupture (MOR) reduced after exposure to the weather for 3 to 9 weeks. There was no significant difference in density and strength properties after 3 weeks of exposure to weather however, after 6 and 9 months of exposure, the density, MOE, and MOR of *B. vulgaris* were significantly different at p<0.05 compared to control.

Table 2 shows the reduction in density and strength of *B. vulgaris* compared to the control. After 3 weeks of exposure, the density increased slightly compared to the control (3.39%), despite the lack of significance at p<0.05, but after 6 weeks of exposure, the density decreased dramatically by roughly 18.41%. After 9 weeks of exposure, the decline in density (17.44%) remained in comparison to the control. The decrease in density could be attributed to photo-oxidation or photochemical degradation of the bamboo surface produced by solar radiation, wetting, and drying of bamboo caused by rainfall, and diurnal and seasonal fluctuations. The density is greatly influenced by the depth of photodegradation and the rate of erosion during weathering [18].

The strength properties of *B. vulgaris* in Table 2 shows the reduction in MOE (19.7-24.27%) and MOR (12.4-16.27%) after 3-6 weeks of exposure compared to the control. The value of MOE (24.17%) and MOR (13.95%) after 9 weeks of exposure was equal to the value after 6 weeks of exposure, even though the reduction of MOR value against control was reduced. Some of the drops in strength qualities are most likely attributable to the reduction in density of bamboo following exposure. As previously stated, the density of the bamboo decreases substantially as the length of exposure increases. The reduction is most likely due to the slow destruction of bamboo lignocellulosic by the weathering process. Many elements, including rainfall, solar radiation, and temperature, influenced the degradation pathways. When exposed to sunlight, the colour of the samples changes and the surface fibres loosen and disintegrate. Discolourations in the surface of bamboo can be noticed in Figure 3 and are described by Williams (2005) [15]. Figure 3 compares *B. vulgaris* samples that were exposed to the weathering process for 3, 6, and 9 weeks to unexposed samples.
4. Conclusion
Weathering was applied to Bambusa vulgaris splits for 3, 6, and 9 weeks. After three weeks of exposure, there was no significant change in the colour of B. vulgaris; however, after six and nine weeks of exposure, there were substantial modifications. The longer the exposure period, the larger the colour shift. Because of the little penetration of UV and visible light into bamboo and the beginning of photochemical processes, changes in bamboo colour are regarded as a superficial phenomenon. A drop in the white value shows that the bamboo's colour is becoming darker. The density, modulus of elasticity (MOE), and modulus of rupture (MOR) of the strength samples were not substantially different from control samples after 3 weeks of weather exposure but were considerably reduced after 6 to 9 weeks. The decline in strength qualities is most likely related to the decrease in the density of bamboo following exposure. After 6- and 9-weeks of exposure, there was no significant difference in colour changes, density, MOE, or MOR of B. vulgaris. The percentage reduction in MOE and MOR increased with the length of exposure. The reduction is most likely due to the slow destruction of bamboo lignocellulosic by the weathering process. Many elements, including rainfall, solar radiation, and temperature, influenced the degradation.

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