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Assessment of Potency of Modifying *Bambusa vulgaris* Strip Colour with Regulated Pressured Method of Dying

Esther Happy Alama[1,*], Nureni Adedapo Adewole[1], Femi Kehinde Owofadeju[1], Deinyefa Godfreee Igbiriki[2], Pabara-Ebiowei Dickson[3], Lucky Oghenerukevwe Wilson[4], Prince Billy[5], Lydia Sinikiem Ezekiel[4]

[1] Department of Wood Products Engineering, Faculty of Technology, University of Ibadan, Oyo State, Nigeria

[2] Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, Hubei Province, China

[3] Department of Pharmaceuticals and Medicinal Chemistry, Faculty of Pharmacy, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

[4] Department of Petroleum, Faculty of Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

[5] Department of Biological Sciences, Niger Delta University, Wilberforce Island, Bayelsa Sate, Nigeria

*E-mail address: alamaestherhappy@gmail.com

ABSTRACT

In response to wood scarcity in Nigeria, this study investigated bamboo as an alternative raw material for interior applications. Bamboo culms from the University of Ibadan were processed into strips and treated with boric acid and sodium hypochlorite solution. Dyeing was done using a pressure method with caustic soda and sodium sulphate. From 35 bamboo culms (average length: 269 cm), the initial recovery rate was 81%, decreasing to 36% after planning. The treatment brightened the bamboo's colour, which varied from dark carton brown to vibrant shades. Moisture content dropped from below 12% to 9.1%, eventually settling below 13% after dyeing. Density increased from 600 kg/m^3 to 664 kg/m^3. Dye penetration was 0.6 mm for black, red, and pink, and 0.55 mm for blue and yellow. The study concludes that using the pressure method approach to infuse dye colour into bamboo culm strips may not make the product suitable for external application due to the minimal penetration depth but can be suitably used to produce items meant for interior application.

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***Keywords*:** *Bambusa vulgaris*, Strip, Colour modification, Aesthetics, Pressure method

1. INTRODUCTION

Continuous scarcity of wood supply for use for structural and non-structural application is further promoting creation of suitable alternatives from the numerous Non-Timber Forest Products (NTFP). Bamboo seems to have stood out as a versatile and sustainable substitute for traditional wood for various end uses (Adewole, 2010). It is technically a giant woody grass and as a tall grass it consists of a hollow culms (Ogedengbe *et al.*, 2008). Bamboo's unique properties includes relatively light weight, flexibility, high tensile strength, eco-friendly, the plant with the highest growth rate globally reaching 30 cm to 100 cm in 24 hours, cheap material for construction sometimes referred to as "The poor man timber" and can be harvested in 3-5years (Selvan and Tripathi, 2017; Ahmad *et al*., 2021; Kumar *et al*., 2023). Therefore its distinguishing factors: comparable strength with wood, wide availability and accessibility, early maturity as well as acceptability must have endeared bamboo to the mind of emerging end users (Adewole and Bello 2013).

Despite bamboo's historical uses being limited to traditional applications in Nigeria, a noticeable shift is occurring in Nigeria towards adopting bamboo for modern interior and furniture manufacturing. This shift is driven by environmental concerns, the push for sustainable resource utilization, and the urgency to find alternatives for the scarcity of wood (Adewole and Bello, 2013). A significant shift is observable in current manufacturing industries, with a deliberate emphasis on incorporating bamboo, particularly in crafting furniture and interior designing which indicates an evolving recognition of bamboo's potential which goes beyond its traditional applications.

However, adapting bamboo for modern application requires processing of its hollow culms into aesthetically appealing strips for use in creating intermediate raw material. Therefore, finding an effective methods to modify bamboo strip colour is a sure way of enhancing its aesthetic features (Depuydt *et al*., 2019; Saikia *et al*., 2015; Yu *et al*., 2014). Non-pressure approach had been tried by to tackle this issue, this study explores the utilization of chemical modification to enhance both the colour and finishings of bamboo products by identifying the most suitable and effective chemical modification method for bamboo and assessing the effect on the physical properties.

2. MATERIALS AND METHODS

The methodology used in this study involved a four-stage process: collection/harvesting, processing bamboo culms, chemical modification, and evaluation of physical properties.

Collection/Harvesting of Bamboo culms

Matured bamboo culms were recovered from a construction sites within the Faculty of Technology, University of Ibadan premises. Recovered culms were carefully selected to make sure it is free from defect and suitable for the required purpose. After recovering of the culms, measurement of some physical characteristics of the bamboo was taken. A total of 35 culms were recovered with an average length of 269 cm. The inner diameter, outer diameter, culms thickness, moisture content of the bamboo culms were measured using meter rule, digital veneer calliper and moisture meter as shown in Figure 1.

Figure 1. Recovery and Determination of Physical Characteristics of Bamboo Culms

Preparation of Uniform Strips and Planning of Bamboo Culms

Recovered culms were cross-cut into a length of 180 to 200 cm using the Circular sawing machine. The glassy bark, the face of the hollow fibre was planned thoroughly using the Combined Thicknessing and Surface Planning Machine to remove the waxy layer and diaphragm to produce a regular dimension strip as shown in Figures 2. However, complications emerged during the planning process using the Combined Thicknessing and Surface Planning Machine, primarily attributed to the small diameter of the bamboo culms. The machine's incapacity to adapt to such slender diameters resulted in significant challenges. Therefore, other alternatives were utilized in the planning process utilizing a smooth plain and the grinding machine as shown in Figure 2. Planned strips were further reduced to a length of length of 20 cm while considering the dimension of novel item to be produced before chemical modification was carried out on the strips the strips.

Figure 2. Planning of Bamboo Strips using Combined Thicknessing and Surface Planning Machine, Smooth Plain and Grinding Machine

Treatment of Uniform Bamboo Strips

This project utilizes the chemical preservation method using Boric acid and it was performed with a open tank in accordance with ASTM D1102. The Boric acid was obtained in its pure form in a whitish-crystalline powder. However, treatment of bamboo using boric acid often produces dull colour monotone products that are hardly attractive upon finishing which may impact negatively on products acceptance especially in its application for furniture and interior upgrade purpose. To counter the darkening effect caused by boric acid treatment in bamboo strips, “Jik” a popular brand of Sodium Hypochlorite (NaOCl) is introduced into the solution.

Determining the Quantity of Boric-Acid

Density of water = $\frac{1g}{mL}$ or $\frac{1kg}{L}$
1 liter = 1000 mL
Amount of Boric Acid (g) = Percentage × Volume of Water (mL)
So to mix 0.5% boric acid in 1000 mL of water
Amount of Boric Acid (g) = 0.005 × 1000 mL = 5g
Therefore, 50g of boric acid is dissolved in 10 litres of water

Determining the Quantity of Sodium Hypochlorite

The concentration of Sodium Hypochlorite used in this project is 1.5%.

1 litre =1000 mL
10 litres = 10000 mL
So to mix 1.5% of 10000 mL = 150 mL of Sodium Hypochlorite in 10 litres of water

Bamboo strips was fully immersed in a solution of 50 grams of boric acid and 150 millilitres of Sodium Hypochlorite to 10 litres of water at room temperature and the bamboo strips are fully immersed for 2 hours, allowing the boric acid and Sodium hypochlorite mixture to penetrate the bamboo fibres thoroughly. The choice of boric acid was based on its non-toxic nature, eco-friendliness, water solubility, and efficacy against borers, termites, and fungi. After the immersion period, the treated bamboo strips are air-dried in an area with proper aeration avoiding contact with the soil. As shown in Figure 3, the drying was carefully carried out to ensure that the bamboo achieves a delicate balance, possessing both structural stability and an appealing visual appearance. The drying of the treated bamboo strips was a deliberate act to ensure the maximum absorption and penetration of the water and dye solution on bamboo strips during the dying process.

Treated bamboo strips were divided into 5 distinct samples which was labelled Sample A, Sample B, Sample C, Sample D, and Sample E. 25 strips of uniform thickness were obtained from each of the samples labelled according to the colours to be dyed. A total of 125 bamboos strips of uniform thicknesses were acquired for the initial colour modification process. Samples of treated bamboo strips were dyed and the process replicated using different colours of dyes (black, blue, yellow, red and pink as shown in Figure 4. Sodium Sulphate (Na_2SO_3) helps to eliminate excess unreacted dye and improves the colourfastness of the dyed material. Caustic Soda (NaOH) is used to adjust the pH of the solution which is crucial for achieving the desired colour and ensuring the effectiveness of the dyeing process (Table 1).

Figure 3. Treatment of Uniform Bamboo Strips Using Boric-acid and Jik (Sodium Hypochlorite) and Air-drying of Treated Bamboo Strips

Figure 4. Sodium Sulphate (Na_2SO_3), Caustic Soda (NaOH), and Dyes


OFF
ON
ZERO
Black
Red
Yellow
Blue
Pink
SF-400

Figure 5. Colour Modification Process of Uniform Bamboo Strips

Table 1. Quantities of Ingredient Used for the Colour

S/N	Ingredient	Weight (g)
1	Caustic Soda	23
2	Dye	8
3	Sodium Sulphate	23

With precision as the guiding principle, 23g portions of Caustic soda, 23g Sodium Sulphate, and 8g of dye was weighed using a precise scale and mixed with 1000 millilitres (1 litter) of boiling water using the pressure cooker. At an initial temperature of 100 °C, the dye is added to the boiling water, closely followed by the addition of weighed Caustic Soda and Sodium Sulphate. The solution was stirred to ensure homogeneity and a batch of uniform laminates was then added into the dye solution. Samples of bamboo strips was pressure cooked at a pressure interval of 0.34, 0.69, 1.03 and 1.38 bar, and at a time interval of 15, 30, 45 and 60 mins. Précised readings of the pressure and volume were recorded at each interval. Once dyed to a maximum pressure of 1.38 bar at a time interval of 60 minutes, the bamboo laminates were removed from the dye solution and laid on a concrete floor to condition at room temperature. It was placing it outdoors, carefully leaning against a wall to air-dry. After drying of bamboo strips to a moisture content <12%, the depth and the depth of penetration was determined. This was done using an abrasive paper of size P50 in sanding the strips, closely monitoring the depth at which the dye has penetrates. Some of the dying processes are shown in Figure 5 and the entire process was repeated for each colour

$$\textbf{The depth of penetration} = \frac{\text{Initial thickness of strips} - \text{ final thickness of strips}}{2}$$

Evaluation of effect of Colour Modification on Physical Properties Bamboo Strips

Colour: Visual observation of colour changes in preserved bamboo strips was conducted. A comparison was made between untreated strips, treated strips, and colour modified strip and the difference in colour between preserved and a control sample was noted.

Moisture Content: a moisture meter was used to determine the percentage of moisture available in untreated strips, treated strips, and colour modified bamboo strips.

Density: Density of bamboo strips was determined using conventional method for untreated strips, treated strips, and colour modified strips. Five bamboo strips were used for this process. The masses of the strips were weighed, and the volume was determined by multiplying the three dimensional sides to assess the effectiveness of the chemical modification.

$$\text{Density } \rho = \frac{\text{Mass}}{Volume}$$

where ρ represents density (kg/m³),
Volume = l × b × d

3. RESULTS AND DISCUSSION

The sample of bamboo culm brought in for scaffolding in the sites at the University of Ibadan was identified as *Bambusa vulgaris* Schrad based on its morphological characteristic. The findings corroborated previous studies by Omoyale (2003), Adewole and Bello (2013) confirming the presence of *Bambusa vulgaris* distinguished by its unique structure, can reach heights of 14 to 20 meters at maturity.

Preparation of Uniform Strips from Bamboo Culms (Ripping and Thicknessing)

Table 2. Statistics of Recovered Bamboo Culms.

Culms parameter	Range/Percentage
Moisture content	<12%
Thickness	7.1 – 11.6 mm
Outer diameter	61.2 – 77.5 mm
Inner diameter	48.4 – 62.8 mm
Length of recovered culms	2140 – 3000 mm
Total number of recovered bamboo culms	35

While processing bamboo culms with woodworking machines, it was observed that the resulting strips displayed varying widths along their length, aligning with the findings of Adewole and Bello, (2013). These variations were linked to challenges encountered during bamboo culms processing with woodworking machinery, leading to heightened energy consumption, labour demands, diminished recovery rates, time loss, and amplified waste production.

Table 3. Bamboo strip recovery index after stripping

Parameters	Value
Number of culms	35
Number of expected strips	210
Number of recovered strips	170
Percentage recovery	80.95%
Percentage wasted	19.05%

The moisture content of the recovered bamboo culms is reported to be less than <12%. The thickness of the bamboo culms ranges from 7.1 mm to 11.6 mm. The outer diameter of the culms falls within the range of 61.2 mm to 77.5 mm. The inner diameter of the culms ranges from 48.4 mm to 62.8 mm.

The recovered culms have lengths ranging from 2140 mm to 3000 mm. A total of 35 culms were recovered for the study which had an average length of 2690 mm. Each culm was ripped into at least 6 strips which was expected to produce 210 stripes, 170 stripes was recovered by theoretical estimation as shown in Table 3.

Percentage Recovered after stripping

Strips recovered = 170
Percentage recovered = (170 / 210) * 100 = 80.95%

Percentage Wasted after Stripping

Wasted strips = 210 - 170 = 40
Percentage wasted = (40 / 210) * 100 = 19.05%

The significant amount wasted is a direct consequence of utilizing woodworking machinery for bamboo conversion in Nigeria, where alternative techniques are lacking. Unfortunately, the cutting blades on these machines are ill-suited for bamboo manipulation

Percentage Recovery after Planning

Percentage Recovery = (61 / 170) × 100%
Percentage Recovery ≈ 35.88%

Percentage Waste after Planning

Percentage Waste = 100% - 35.88%
Percentage Waste ≈ 64.12%

Table 4. Bamboo strip recovery index after planning.

Parameters	Values
Strips thickness before planning	7.1 – 11.6 mm
Average thickness after planning	3 – 8 mm
Number of recovered strip before planning	170
Number of recovered strip after planning	61
Percentage recovery	35.88%
Percentage waste	64.12%

Effect of Treatment on Physical Characteristics of Bamboo strips

The following were observations when bamboo strips where treated in a solution of boric acid and Sodium hypochlorite:

Colour: Bleaching bamboo to a lighter shade before dyeing is essential for achieving consistent, vibrant, and controlled colour results when using dye colours. It helps to neutralize the bamboo's natural colour variations and prepares strips for optimal dye penetration and colour absorption. Changes in colour of bamboo strips bamboo strips was observed carefully in every stage and recorded. Bamboo strips treated with 50 grams of boric acid and 150 millilitres of Jik to 10 litres of water at room temperature were observed to produce a brighter and more enhanced shade a when compared to untreated strips. Treated strips further underwent a colour modification process using Sodium Sulphate (Na_2SO_3), Caustic Soda (NaOH), and Dyes of different colours which produced vibrant coloured strips as shown in Fig. 6 below.

Untreated strips

Treated strips

Dyed strips

Figure 6. Colour Variation between Treated, Untreated and Colour Modified Bamboo strips.

Moisture content: The percentage of moisture content in the bamboo was determined at intervals using a moisture meter and it was observed that recovered bamboo culms have a moisture content less than <12%. After converting bamboo culms into uniform strips, there was a reduction in the moisture content as it was recorded to be an average of 9.6% After chemical treatment of bamboo strips with 50 grams of boric acid and 150 millilitres of Jik to 10 litres of water, it was left to air-dry in an area with proper aeration, the moisture reading was observed to further decrease to an average moisture content of 9.1%, before colour modification was carried out. After the colour modification (using are Sodium Sulphate (Na_2SO_3), Caustic Soda (NaOH), and Dyes of different colours) which was heated at different pressure using a pressure cooker, strips laid on the floor and left to condition at room temperature and was later air-dried under a shade with proper aeration and moisture readings were recorded to be below <13% before undergoing lamination process.

Density: the density of bamboo strips was also determined at intervals as five samples were obtained of untreated and the density determined as sown in the Table 7. It was observed that there was a slight reduction in the density of chemically treated bamboo strips as it was compared to that of the untreated strips.
The process utilized an established equation as depicted below

$$\text{Density } \rho = \frac{\text{Mass}}{Volume}$$

where ρ represents density (kg/m³), Volume = l × b × d

From Table 5 given above, the average mass of untreated bamboo strips is 0.0152 kg while that of the treated strips is slightly higher at 0.0154 kg. The mass values for treated bamboo strips are very close to those of the untreated strips, indicating that the chemical treatment process does not significantly alter the mass of the bamboo strips. The average mass of colour modified bamboo strips is 0.0174 kg.

The colour modification process seems to increase the mass of the bamboo strips slightly, as indicated by the higher average mass compared to both untreated and treated strips.

Table 5. Mass of Bamboo Strips.

	Mass of untreated bamboo strips (kg)	Mass of treated bamboo strips (kg)	Mass of colour modified bamboo strips (kg)
Sample A	0.014	0.015	0.016
Sample B	0.025	0.025	0.028
Sample C	0.014	0.014	0.015
Sample D	0.015	0.015	0.016
Sample E	0.008	0.008	0.012
Average mass	**0.0152**	**0.0154**	**0.0174**

Table 6. Determination of volume of bamboo strips.

	Volume of untreated bamboo strips (m)	Volume of treated bamboo strips (m)	Volume of colour modified bamboo strips (m)
Sample A	0.218*0.021*0.0047	0.22*0.022*0.0048	0.21*0.021*0.0048
Sample B	0.25*0.028*0.0057	0.22*0.028*0.0057	0.22*0.028*0.0059
Sample C	0.225*0.021*0.0047	0.225*0.028*0.0046	0.22*0.022*0.0048
Sample D	0.22*0.0189*0.0057	0.22*0.019*0.0057	0.22*0.020*0.0057
Sample E	0.21*0.0229*0.0053	0.21*0.023*0.0053	0.23*0.019*0.0054

Table 6 indicates that the process of colour modification also influences the volume of the bamboo strips. For most samples, colour modification results in a slight increase in volume, suggesting that the dyeing process may cause the bamboo to expand slightly. This trend is not uniform across all samples, as some strips show minor decreases in volume post-modification. However, on average, colour modification tends to increase the volume slightly.

The Table 7 provided above which is also represented in the chart shows that treatment generally tends to increase the density of bamboo strips, except in the case of Samples A, D, and E where the increase is marginal or the density slightly decreases after chemical treatment with boric-acid and Sodium hypochlorite which is as a result of leaching of the starch content during the duration of treatment. Colour modification generally increases the density for most samples (A, B, D and E). The chemical treatments (both initial and colour modification) tend to increase the density of the bamboo strips, potentially indicating that the chemicals are adding mass to the strips or causing some form of densification.

Table 7. Density determination of bamboo strips.

	Density of untreated bamboo strips (kg/m³)	**Density of treated bamboo strips (kg/m³)**	**Density of colour modified bamboo strips (kg/m³)**
Sample A	651	646	756
Sample B	627	712	770
Sample C	630	731	646
Sample D	633	630	638
Sample E	313	308	508
Average density	**600**	**605.4**	**664**

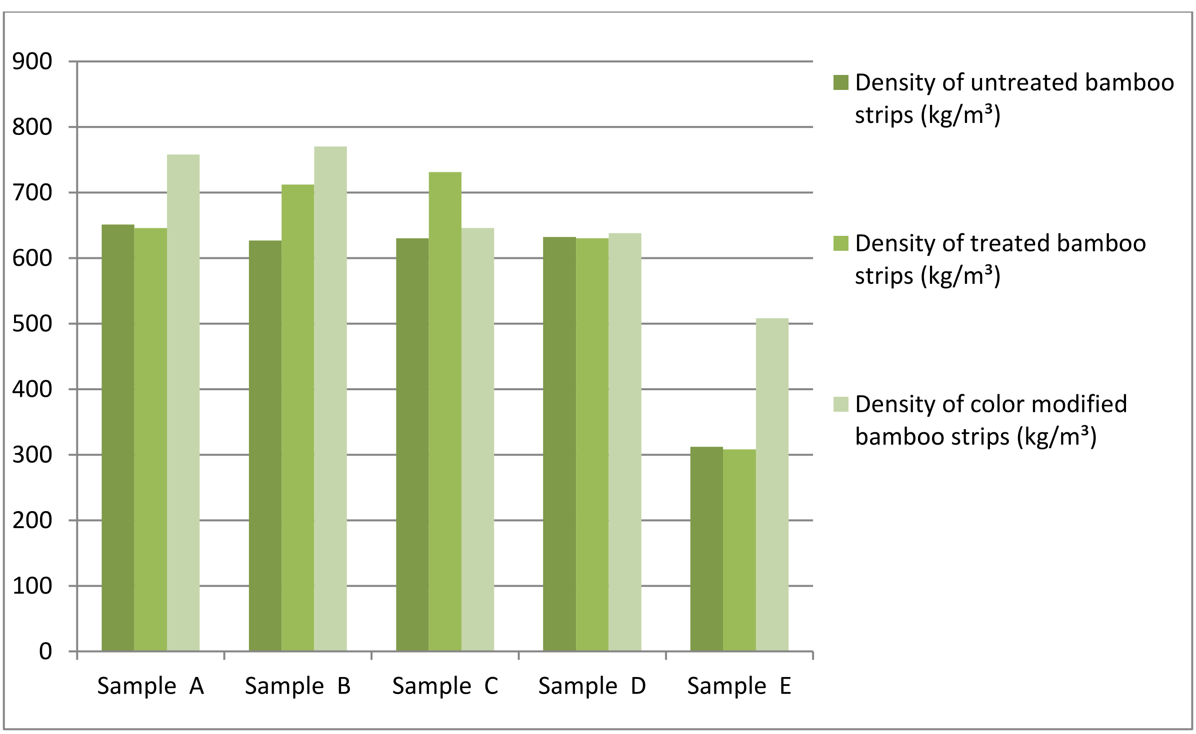

Figure 7. Chart Showing Increase in Density of Bamboo Strips

Depth of Penetration

Based on the formula provided, the depth of penetration was obtained for each strip as follows: Initial thickness of the strip was measured and recorded. The strip was dyed and then sanded using an abrasive paper (P50) until the dye was no longer visible. The final thickness of the strip was measured and recorded. The depth of penetration was calculated using the formula:

$$\text{The depth of penetration} = \frac{\text{Initial thickness of strips} - \text{final thickness of strips}}{2}$$

Depth of penetration for black colour = $\frac{4.1-2.9}{2}$ = 0.6 mm

Depth of penetration for blue colour = $\frac{4.1-3.0}{2}$ = 0.55 mm

Depth of penetration for red colour = $\frac{4.1-2.9}{2}$ = 0.6 mm

Depth of penetration for pink colour = $\frac{4.1-2.9}{2}$ = 0.6 mm

Depth of penetration for yellow colour = $\frac{4.1-3.0}{2}$ = 0.55 mm

The results show that the depth of penetration varies among the different colours, with black, red, and pink having a deeper penetration (0.6 mm) compared to blue and yellow (0.55 mm). This variation can be attributed to several factors: Colour intensity (darker colours need more dye molecules); Natural variations in the bamboo material; Small differences in the dyeing.

4. CONCLUSIONS

This study successfully enhanced bamboo properties through chemical modification, achieving: 81% strip recovery rate after ripping and 36% after planning, improved colour with a brighter shade and depth of penetration of 0.6 mm (black, red, pink) and 0.55 mm (blue, yellow), reduced moisture content from <12% to 9.1% after chemical treatment and <13% after colour modification, increased density from 600 kg/m^3 to 664 kg/m^3. The treated strips showed enhanced aesthetic quality and longevity, though dye penetration depth was inadequate.

The research outcomes was found suitable for applications in crafts and novel items, demonstrating the applicability of chemically treated bamboo in interior design, fulfilling the study's objectives, affirming the effectiveness of chemical modification, identifying areas for further development, and promoting the use of bamboo as a sustainable material, contributing to sustainability, economic advancement, and innovation in wood industries in Nigeria.

To further improve on the chemical modification process, recommendation includes optimizing chemical treatment penetration, conducting comparative studies with different types of dyes or chemical treatments to determine the most effective and reliable methods for enhancing the physical properties of bamboo strips, collaborate with industry partners, furniture manufacturers, or interior designers to gain insights into market trends, consumer preferences, and industry standards, document and share findings, methodologies, and outcomes in academic publications, industry reports, or conference presentations, and promoting continuous exploration and innovation in bamboo industries.

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