

## WEIGHT LOSS OF CHEMICALLY MODIFIED KELEMPAYAN (*Neolamarckia cadamba*) WOOD PARTICLES USING ALKALINE

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**Abstract:** *The weight loss behaviour of Kelempayan (*Neolamarckia cadamba*) wood particles that have undergone alkaline chemical alteration is examined in this work. Two particle sizes (0.5 mm and 1.0 mm) were treated with sodium hydroxide (NaOH) solutions at concentrations of 0.5, 1, and 2% for 60 minutes at 30 and 90°C. Particle mass measurements obtained before and after treatment were used to calculate weight reduction. The results showed that the weight loss of the samples was significantly influenced by temperature, NaOH concentration, and particle size ( $p < 0.05$ ), with smaller particles treated at higher NaOH concentrations experiencing the highest weight losses. Temperature had no significant effect on weight loss, although slightly higher weight loss was observed at 90°C. The particle size and weight loss of the samples showed a strong negative correlation ( $r = -0.96$ ) according to statistical analysis, indicating that smaller particles are more vulnerable to alkaline degradation because of their larger surface area-to-volume ratio. 0.5 mm particles treated with 2% NaOH at 90°C showed the greatest weight loss (21.00%), whereas 1.0 mm particles treated with 0.5% NaOH at 30°C showed the least weight loss (9.33%). These results emphasise how crucial it is to optimize alkaline treatment conditions to balance minimal material loss with efficient hemicellulose, lignin, and extractive removal. This work establishes distinct correlations between temperature, NaOH concentration, and particle size, offering quantitative insight into the degrading behaviour of Kelempayan under various processing settings. These results provide useful recommendations for enhancing the performance consistency of particleboard and other wood-based composites and for optimising raw material treatment.*

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## 1. Introduction

Tropical species have the potential to be sustainable raw materials for engineered wood products like particleboard because of their high biomass yield and quick growth rate, which improve land-use efficiency. Because of its low wood density, rapid rotation cycle (6 to 8 years), and potential for laminated, particleboard, and fibreboard applications, *Neolamarckia cadamba*, commonly known as Kelempayan, has drawn attention in Southeast Asia [14]. Growing it also benefits rural communities and reduces pressure on natural forests, which aligns with broader environmental objectives.

However, the relatively high hemicellulose, lignin, and extractives content in Kelempayan can jeopardise adhesive bonding, dimensional stability, and the composite's long-term durability [10]. To mitigate these issues, alkaline chemical modification, particularly with sodium hydroxide (NaOH), is commonly employed. This process improves fibre wettability and adhesion while increasing surface roughness and removing extractives and amorphous hemicellulose [17].

One important alkaline treatment parameter that shows the degree of chemical removal and cell wall disintegration is weight loss [10]. While some weight loss may enhance composite performance, excessive deterioration can reduce material yield and jeopardise structural integrity. The amount of weight loss is influenced by treatment factors such as temperature, NaOH concentration, and particle size. Smaller particles usually lose

more weight due to their higher surface area-to-volume ratio, which encourages chemical penetration [12]. Higher NaOH concentrations and temperatures speed up the removal of hemicellulose and the solubilisation of lignin, but also pose an increased risk of cellulose damage [17].

*Neolamarckia cadamba* is still underrepresented in the literature, despite extensive study on the alkaline alteration of fibres such as kenaf, jute, and oil palm [7]. Previous studies have largely focused on enhancing mechanical and bonding performance, with little attention paid to how treatment parameters impact weight loss and yield.

The effects of alkaline treatment vary greatly depending on the anatomical and chemical properties of the species, even though it is known to partially degrade cellulose and impair fibre integrity. These reactions are still not well known for Kelempayan, a fast-growing tropical hardwood with a characteristic low density and fibre structure. In order to identify processing parameters that limit structural damage while successfully removing non-cellulosic components, this study attempts to comprehensively assess the impact of particle size, NaOH concentration, and treatment temperature on weight loss.

*Neolamarckia cadamba* (Kelempayan) is gaining popularity, but little is known about how alkaline treatment parameters affect material degradation and yield, especially weight loss. In order to determine the ideal circumstances that strike a balance between efficient modification and the least amount of material loss, this study assessed the effects of particle size, NaOH concentration, and treatment temperature

on weight loss. The results offer a foundation for enhancing processing effectiveness and promoting the sustainable use of tropical hardwoods that develop quickly in composite applications.

## 2. Materials and Methods

### 2.1. General Aspects

Wood particles with a size fraction of 0.5 to 1.0 mm were used in this study. For each treatment, 1 g of oven-dry particles was immersed in 6 mL of distilled water, corresponding to a solid-to-liquid ratio of 1:6 (w/v) treated with 0.5, 1, and 2% NaOH solution. All treatments were conducted in triplicate to ensure reproducibility.

### 2.2. Preparation of NaOH Solution

The method described by Harris and Lucy [5] was used to prepare the sodium hydroxide solution. A clean beaker was filled with around 240 g of NaOH powder that had been weighed on a balance. The beaker was then filled with 500 ml of distilled water. Before being poured into a 1-litre volumetric flask, the mixture was stirred to make sure the NaOH powder was completely dissolved. One litre of distilled water was added and mixed thoroughly. While 24 ml of the NaOH solution was pipetted into a conical flask, the standard hydrochloric acid (HCl) solution (0.5 M) was put in the burette. The NaOH solution was titrated using standard hydrochloric acid (0.5 M) to determine its exact concentration using acid–base standardisation.

After adding two to three drops of phenolphthalein indicator, the standard hydrochloric acid was titrated to the end point. The solution's colour shifted from red violet to colourless at the end. All the

titration volume was recorded and computed using Equation (1), after the titration was repeated until three consecutive readings.

$$M_1 \cdot V_1 = M_2 \cdot V_2 \quad (1)$$

where:

$M_1$  is the molarity of NaOH solution [M];

$M_2$  – the molarity of HCl [M];

$V_1$  – the volume of NaOH solution [ml];

$V_2$  – the volume of HCl [ml].

### 2.3. NaOH Treatment

The sodium hydroxide treatment was modified using the procedure outlined in Li and Du [11]. Particles were treated with 0.5, 1, and 2% NaOH solution at a ratio of 1 g of wood particles to 6 ml of distilled water during the initial investigation. The treatment was carried out in a rotary digester that was kept between 30 and 90°C. The wood particles were weighed, put in a rotary digester, and then soaked in NaOH before being dissolved in distilled water. For 60-minute immersion intervals, the digester was rotated. Following their removal from the digester, the samples were rinsed under running water to neutralise any remaining NaOH and bring their pH down to 7. The samples were then oven dried at 80°C until they had about 5% moisture. In order to measure weight loss directly, particles were measured both before and after treatments, after oven drying. Equation (2) was used to compute the weight loss of particles for each treatment to determine the percentage of dissolved particles.

$$W_L = \frac{w_I - w_F}{w_I} \cdot 100 \quad (2)$$

where:

$W_L$  is the weight loss [%];

$w_F$  – the final weight [g];

$w_I$  – the initial weight [g].

Equation (2) was used to compute weight loss, which was then expressed as a percentage of dissolved particles. Each experiment was carried out in triplicate, and the effects of temperature, NaOH concentration, and particle size were assessed using analysis of variance (ANOVA), with significance set at  $p < 0.05$ .

### 3. Results and Discussion

#### 3.1. Weight Loss

One of the key components of alkaline treatment is wood weight loss, which is sometimes referred to as a quality indicator. Weight loss with alkaline treatment is dependent on wood species,

alkaline content, temperature, and time, according to a study by several authors. Particle diameters of 0.5 and 1.0 mm were used to compare and discuss weight loss percentages based on treatment temperatures (30 and 90°C) and treatment concentrations (0.5, 1, and 2%) (Table 1). After soaking in an alkaline solution, the percentage of weight loss samples data varied from 9.33 to 21%. When compared to other samples, the percentage weight loss of particles with a size of 0.5 mm at 90°C and treated with 2% alkaline concentration was generally higher.

However, the lowest percentage weight loss of the samples was seen in particles with a particle size of 1.0 mm that were immersed in 0.5% alkaline concentration at 30°C. It is evident that increasing the alkaline concentration from 0.5 to 2% boosted the percentage weight loss of the samples.

*Comparison weight loss of the samples from variation of particle sizes, temperatures, and alkaline concentrations*

Table 1

Particle size [mm]	Temperature [°C]	Alkaline concentration [%]	Weight loss [%]
0.5	30	0.5	19.00
0.5	30	1	19.00
0.5	30	2	20.33
0.5	90	0.5	19.33
0.5	90	1	18.33
0.5	90	2	21.00
1.0	30	0.5	9.33
1.0	30	1	10.00
1.0	30	2	11.00
1.0	90	0.5	10.67
1.0	90	1.0	11.67
1.0	90	2.0	13.00

Note: Values are average of three determinations.

Compared to 0.5 mm, the percentage of weight loss from particle sizes of 1.0 mm was significantly lower. Because of their smaller surface area, which restricts NaOH penetration and reactivity with cell wall components, 1.0 mm particles exhibited noticeably less weight loss than 0.5 mm particles. This pattern is in keeping with earlier research, which showed that smaller particles or fibres lost more mass because hemicellulose and lignin were more accessible to alkaline assault [2]. Furthermore, the weight loss of the samples range found in this study is within the generally reported range for lignocellulosic materials treated with alkaline, which usually varies based on the qualities of the raw material and the intensity of the treatment [9].

### 3.2. Statistical Significance

Table 2 displays the results of the ANOVA on the effects of temperature, alkaline concentration, particle size, and their interactions with the percentage weight loss of the samples. Particle size, alkaline concentration, and temperature were found to have a significant impact on the percentage weight loss of the samples. Particle size and alkaline concentration interaction effects did not significantly alter the percentage of weight loss. However, statistical analysis showed that the interaction between temperature and particle size had a substantial impact. There was no significant difference in the percentage of weight loss when alkaline content and temperature interacted. Overall, there was no significant interaction between weight loss and temperature, alkaline content or particle size.

Summary of the ANOVA on the percentage of weight loss

Table 2

SOV	Df	Weight loss [%]
PS	1	1633.33*
CONC	2	34.00*
TEMP	1	24.34ns
PS × CONC	2	2.43ns
PS × TEMP	1	6.89*
CONC × TEMP	2	1.34ns
PS × CONC × TEMP	2	1.41ns

Note: SOV is the source of variance, Df – the degree of freedom, PS – the particle size, CONC – the alkaline concentration, TEMP – the temperature, ns – not significant at  $p > 0.05$ , \* Significant at  $p < 0.05$ .

### 3.3. Effects of Particle Size on Weight Loss

The effect of particle size on weight loss is depicted in Figure 1. Particle size was found to have a significant effect on the weight loss of the samples, according to

the *t-test*. This was further demonstrated by the correlation analysis, which showed that particle size and weight loss of the samples have a significant negative correlation ( $r = -0.96^*$  – Table 4).

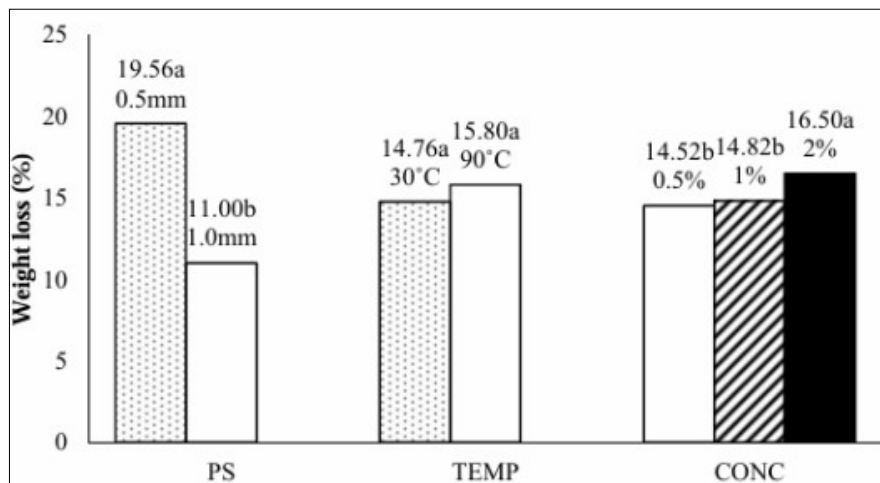


Fig. 1. Effects of particle size (PS), temperature (TEMP), and alkaline concentration (CONC) on weight loss

The degradation of hemicellulose, lignin, and extractives may be the cause of the weight loss in samples treated with alkaline [20]. When exposed to alkaline conditions, these components were more likely to deteriorate. This could be explained by the

fact that smaller particles will absorb more alkaline substances since they have a higher surface area-to-volume ratio than larger particles (Table 3), which causes more degradation of wood components that are unstable in alkaline solutions.

Surface area-to-volume ratio of 0.5 mm and 1.0 mm particles

Table 3

Particle size	L [mm]	T [mm]	W [mm]	SR	ASR	Vol. [mm <sup>3</sup> ]	SA [mm <sup>2</sup> ]	SA/Vol. [mm <sup>-1</sup> ]
0.5	1.62	0.32	0.77	5.01	2.11	0.40	4.02	10.05
1.0	6.30	0.33	0.68	19.17	9.31	1.41	13.18	9.31

Note: L is the length, T – the thickness, W – the width, SR – the slenderness ratio, ASR – the aspect ratio, Vol. – the volume, SA – the surface area.

### 3.4. Effects of Temperature on Weight Loss

There is no obvious correlation between the temperature effects and the weight loss of the samples (Figure 1). The findings showed that rising temperatures had little

effect on the proportion weight loss of the samples. It demonstrates that the weight loss of the samples was slightly higher at 90°C than at 30°C. The temperature and weight loss of the samples had insignificant positive correlation ( $r = 0.12ns$ ), according to the correlation analysis (Table 4).

*Correlation coefficients of the effects of particle size,  
alkaline concentration, and temperature on weight loss*

Table 4

Variable	Weight loss [%]
PS	-0.96*
CONC	0.18*
TEMP	0.12ns

Note: PS is the particle size, CONC – the alkaline concentration, TEMP – the temperature, ns – not significant, \*Correlation is significant at the 0.05 level.

According to Baskaran et al. [1], thermal degradation of hemicellulose, along with the evaporation of water, carbon dioxide, and other volatile components, contributed to the slightly increased weight loss observed. Because hemicellulose contains acetyl groups, it is less stable and breaks down faster in an alkaline environment than cellulose and lignin [18]. The evaporation of low-molecular-weight volatile chemicals and the elimination of bound and free moisture are most likely responsible for the slightly greater weight loss of the samples seen at 90°C in Figure 1. Major wood components like cellulose and hemicellulose are unlikely to undergo considerable thermal deterioration at this temperature because these polymers usually start to break down at considerably higher temperatures [19]. Therefore, physical mechanisms involving moisture loss and the release of easily volatile extractives, rather than chemical degradation, should be responsible for the observed alterations [4, 6]. Wood chemistry investigations show that mass loss is mostly controlled by water evaporation below 100°C rather than the structural degradation of wood polymers [15].

### 3.5. Effects of Alkaline Concentration on Weight Loss

The impact of alkaline concentration on the percentage weight loss of the samples is displayed in Figure 1. As alkaline content increased, so did the percentage weight loss of the samples. There was no significant difference in the weight loss of the samples between concentrations of 0.5 and 1%. On the other hand, the weight loss of the samples was significantly impacted by a 2% alkaline content ( $p < 0.05$ ). Alkaline concentration and weight loss percentage have a significantly positive correlation ( $r = 0.18^*$ ), according to the correlation study (Table 4). Depending on the concentration, alkaline solutions dissolve a portion of the wood material. The alkaline treatment caused the chemical constituents of wood, including hemicellulose, lignin, and extractives, to deteriorate. Following treatment with alkaline solutions, non-structural wood components or wood extractives, such as colours, tannins, resins, simple sugar, and fatty acids, also decomposed [3].

According to Ndazi et al. [13], cellulose was less susceptible to an alkaline solution than lignin and hemicellulose. According to a prior study, cellulose would not hydrolyse at a concentration of 17.5% NaOH because

it is resistant to alkaline [8]. As the concentration of alkaline increased, the destruction of wood materials deepened. Shaha et al. [16] found the same results with alkaline treatment. Yasar and Icel [20] discovered that while the particles cellulose content increased, lignin, hemicellulose, and extractive consistently decreased as the concentration increased during the alkaline treatment.

#### 4. Conclusions

This study showed that the weight loss behaviour of Kelempayan wood particles is considerably influenced by alkaline chemical treatment using sodium hydroxide. The findings showed that:

- Particle size had the biggest impact, with smaller particles (0.5 mm) losing more weight because of their larger surface area-to-volume ratio;
- Alkaline concentration was also important; at higher temperatures, 2% NaOH caused the most deterioration;
- At 90°C, temperature boosted degradation even though it had less of an impact than particle size and concentration; this was probably because of increased hemicellulose and lignin breakdown;
- 0.5 mm particles treated with 2% NaOH at 90°C showed the greatest weight loss (21.00%), whereas 1.0 mm particles treated with 0.5% NaOH at 30°C showed the lowest weight loss (9.33%), a considerable negative correlation ( $r = -0.96$ ) between particle size and weight loss was confirmed by statistical analysis, highlighting the vulnerability of finer particles to chemical degradation.

These results emphasise how crucial it is to optimise alkaline treatment to maintain particle integrity and composite performance by striking a balance between component removal and minimal material loss. This is essential for increasing material efficiency and promoting the sustainable use of tropical hardwoods that grow quickly. Future research should evaluate the effects of treatment conditions on composite characteristics and scalability and validate these mechanisms through direct characterisation (e.g., FTIR, XRD).

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