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Influence of Adding Silicon Dioxide in Particleboard from Teak Sawdust to Reduce Water Absorption and Thickness Swelling

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ABSTRACT

This study investigated the influence of silicon dioxide (SiO_2) addition to particleboard from teak sawdust to reduce water absorption and thickness swelling using standard tests of physical and mechanical properties. The experiment had a completely randomized design with four treatments (SiO_2 concentrations of 5%, 3%, 1%, and 0%), each with three replicates, for a total of 12 conditions. The results showed that 1% concentration was the optimal concentration to reduce both water absorption (32.42% ± 1.78%) and thickness swelling (8.65% ± 1.16%). The product passed the standard tests for physical and mechanical properties, which reduced the cost of the SiO_2 content for particleboard processing. These results suggest that SiO_2 can resist moisture content but may slightly reduce strength.

Keywords: concentration, density, mechanical property, moisture content, physical property, silicon dioxide, *Tectona grandis*

1. INTRODUCTION

Forest resources in Thailand are dwindling because of the rising demand for their utilization (Flaherty and Filipchuk, 1993; Rout, 2018; Salam *et al*., 2006). Wood is a renewable and sustainable material that has remained a vital resource from the past to the present (Blanchet and Breton, 2020; Goldhahn *et al*., 2021; Schubert *et al*., 2023). The development of wood utilization has been continuous, encompassing activities such as logging, sawmilling, and wood processing (Borz *et al*., 2021; Kunickaya *et al*., 2022; Namuene and Egbe, 2022) for products that meet consumer needs. In northern Thailand, teak (*Tectona grandis*), a member of the Lamiaceae family, is commonly used (Asanok *et al*., 2024; Li and Olmstead, 2017). Teak wood has high quality, medium density (D), moderate strength, and high durability (Miranda *et al*., 2011; Seta *et al*., 2023; Wanneng *et al*., 2014). In addition, teak wood has beautiful grains and is easy to process, making it popular for creating various types of furniture (Bouaphavong *et al*., 2023; Damayanti *et al*., 2018; Wanneng *et al.,* 2021).

Phrae Province is a key hub for the teak industry in northern Thailand, ranging from small-scale household

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production to large factories that export teak wood products nationwide (Kaakkurivaara *et al*., 2022; Kanthawong *et al*., 2023). This favorable environment makes Phrae a prime source of high-quality teak, involving a significant local population in teak furniture production and distribution (Buareal *et al*., 2020; Thulasidas and Bhat, 2012). Consequently, many people in the province are involved in the production and sale of teakwood-based furniture. Popular furniture products include tables, chairs, beds, cabinets, altar tables, Buddhist pedestals, and various household items such as wooden trays, coasters, wooden toys, and bowls (Klinpikul and Srichandr, 2009; Laemlaksakul and Sangsai, 2013; Scott, 2008). As a result, the production of these furniture items generates a substantial amount of wood scrap and teak sawdust (Egwutvongsa, 2023; Griyanitasari and Pahlawan, 2020) primarily disposed of through burning. This practice significantly contributes to air pollution, including fine particulate matter (PM2.5; ChooChuay *et al*., 2020; Peter and Nagendra, 2021; Takaoka *et al*., 2016). This is a significant factor affecting the respiratory system of people in the area, leading to various associated health problems such as itching, respiratory issues, and lung cancer (Liu *et al.,* 2017, 2022; Nakhjirgan *et al.,* 2019; Sukuman *et al*., 2023; Zhang *et al.,* 2022).

Particleboard from teak sawdust is a sustainable alternative to traditional wood with the aim of reducing waste (Chauhan *et al.,* 2021; Ikubanni *et al*., 2018). However, challenges arise, such as water absorption (WA) and swelling, owing to the high thickness of the panels used in the market, which reduces their lifespan (Chaydarreh *et al*., 2022; Istek *et al*., 2019; Nourbakhsh, 2010; Rivela *et al*., 2006; Viswanathan *et al.,* 2000) and leading to issues such as mold and termite infestation (Acda and Cabangon, 2013; Chotikhun *et al*., 2018; Garzón-Barrero *et al.,* 2016). Researchers have addressed this issue by incorporating silicone dioxide (SiO_2) into particleboards to reduce these problems. SiO_2 is a hydrophobic substance capable of resisting moisture and has a very low risk of toxicity. It is in the powder form, making it easy to handle and inexpensive. When mixed with an adhesive during the panel production process, SiO_2 improves the water resistance and dimensional stability (Alam *et al.,* 2014; Boostani and Modirrousta, 2016; Fu *et al*., 2023; Karim *et al*., 2017; Nazerian *et al.,* 2018; Nortuy *et al*., 2018). Researchers have been interested in using teak sawdust waste to produce particleboards by adding an appropriate amount of SiO_2 to reduce WA and thickness swelling (TS). We conducted tests on both the physical and mechanical properties according to the standards used for compressed wood panels. This serves as a strategy to utilize leftover waste and reduce waste accumulation in communities, which causes various diseases. Moreover, this approach could lead to sustainable industrial development.

2. MATERIALS and METHODS

2.1. Wood sample preparation

Teak sawdust from a private teak plantation was obtained from a wood factory in the Sungmen District, Phrae Province, Thailand, as shown in Fig. 1. The particleboard was processed, and its properties were tested at the Maejo University Phrae Campus, Phrae Province, Thailand. The sawdust was screened using a sieve with

Fig. 1. Teak sawdust of a private teak plantation.

a diameter of 7 mm. The mixture was then dried to adjust its moisture content (MC) to approximately 10%. After that, the urea formaldehyde adhesive (viscosity at 30℃ ranges from 200–240 centipoise, specific gravity at 30℃ ranges from 1.28–1.31, and pH ranges from 8.0–9.5) from Thai Chemical Corporation (Samutprakarn, Thailand), is mixed with a quantity of 10% of the dry weight of the wood piece, along with ammonium chloride (Molecular Weight is 53.49 g/mol and pH is 5) from Thai Chemical Corporation used as a hardening agent, which constitutes 2% of the adhesive weight and SiO_2 from Krungthepchemi (Bangkok, Thailand) of 5%, 3%, 1%, and 0% of the adhesive weight per board. The particles were formed into a single-layer panel using a forming box (450 × 450 mm). The particles were then sprayed and mixed in an adhesive mixer for 5 min. Afterwards, it was hot pressed at a pressure of 35 kg per square cm with a pressing temperature of 120℃ for 5 min (the desired D is approximately 680 kg/m^3), then all boards were conditioned in a humidity-controlled room at 25℃ for 7 d or until the weight of the particleboard remains constant as shown in Fig. 2. The experiment

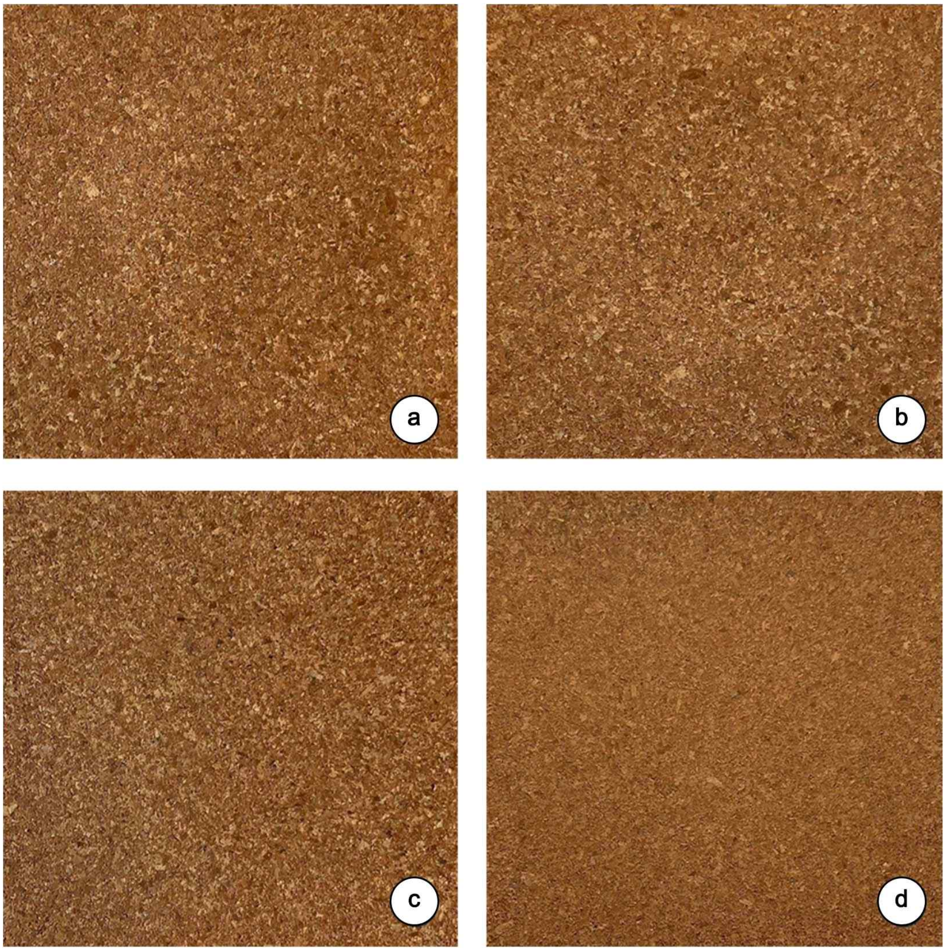

Fig. 2. Particleboard from teak sawdust with different concentrations of SiO_2. (a) 5%, (b) 3%, (c) 1%, and (d) 0%. SiO_2: silicone dioxide.

had a completely randomized design with four treatments (SiO_2 concentrations of 5%, 3%, 1%, and 0%), and there were 12 conditions with three replicates per treatment.

2.2. Data collection

Particleboards were evaluated according to the JIS A5908: Japanese Industrial Standard for Particleboards (JIS, 2003). The physical properties of the particleboard included the MC, D, WA, and TS. The samples were evaluated with dimensions of 50 mm × 50 mm × 10 mm. The MC and D were dried at 103 ± 2℃ for 24 hours, The change in MC was determined as the difference between before and after treatment. MC and D were calculated from the weight and volume using Equations (1) and (2), respectively:

$$MC\ (\%) = (M_1 - M_2) / M_2 \times 100 \tag{1}$$

$$D\ (kg/m^3) = (W_1 / V) \times 10^6 \tag{2}$$

Where M_1 and M_2 are the weights in g before and after treatment, respectively, and V is the volume of the sample in mm^3.

WA and TS were immersed in water for 24 h at room temperature. The values were then estimated based on the differences in the thickness and weight of the specimens before and after water immersion. WA and TS were computed according to Equations (3) and (4):

$$WA\ (\%) = [(W_2 - W_1) / W_1] \times 100 \tag{3}$$

$$TS\ (\%) = [(T_2 - T_1) / T_1] \times 100 \tag{4}$$

Where W_1 and W_2 are the weights before and after immersion, respectively, in grams, and T_1 and T_2 are the thicknesses before and after immersion, respectively, in millimeters.

The mechanical properties of particleboard include internal bonding (IB), modulus of rupture (MOR), and modulus of elasticity (MOE). The IB samples were evaluated on a 50 mm × 50 mm × 10 mm plate, and the tensile strength was tested using a universal testing machine. The IB was calculated according to Equation (5).

$$IB\ (MPa) = F / (W \times L) \tag{5}$$

Where F is the maximum load (N), W is the width of the sample (mm), and L is the length (mm).

The MOR and MOE samples measured 200 mm × 50 mm × 10 mm. The span was set to 150 mm, and the loading speed was set to 10 mm/min using a universal testing machine. The MOR and MOE were calculated using Equations (6) and (7):

$$MOR\ (MPa) = (3 \times P_{max} \times L) / (2 \times b \times h^2). \tag{6}$$

$$MOE\ (MPa) = (P \times L^3) / (4 \times D \times b \times h^3). \tag{7}$$

Where P denotes the load in N, P_{max} denotes the maximum load in N, L denotes the span in mm, b denotes the breadth in mm, h denotes the depth of the test specimen in mm, and D denotes the deflection at the proportionality limit in mm.

2.3. Data analysis

Statistical differences in MC, D, WA, TS, IB, MOR, and MOE between treatments were analyzed using one-way analysis of variance (ANOVA), followed by Duncan's new multiple range test. The physical and mechanical properties of the particleboard were determined using SPSS for Windows (version 26.0, IBM, Armonk, NY, USA).

3. RESULTS and DISCUSSION

3.1. Physical properties with the addition of silicone dioxide in particleboard from teak sawdust

The MC of the particleboard was less than 12%. The lowest content was found with 5% concentration (7.83 ± 5.72%), followed by 3% concentration (8.60 ± 3.08%), 1% concentration (8.94 ± 4.75%), and 0% concentration (9.89 ± 1.98%); these contents were all insignificant ($p < 0.05$). Moreover, the D of the particleboard ranged from to 400–900 kg/m^3. The highest D was found with 5% concentration (689.92 ± 21.20 kg/m^3), followed by 3% concentration (688.90 ± 20.61 kg/m^3), 1% concentration (686.39 ± 22.37 kg/m^3), and 0% concentration (685.12 ± 29.81 kg/m^3); these densities were all insignificant ($p < 0.05$). In contrast, the WA of particleboard was less than 40%. The lowest WA was found with 5% concentration (30.98 ± 2.94%), followed by 3% concentration (32.03 ± 1.24%), and 1% concentration (32.42 ± 1.78%), these WAs were all significant ($p < 0.05$) compared to the 0% concentration (38.83 ± 2.89%). The swelling thickness of the particleboard iwas < 12%. The lowest TS was found with 5% concentration (7.73 ± 1.12%), followed by 3% concentration (8.36 ± 1.07%), and 1% concentration (8.65 ± 1.16%); these WAs were all significant ($p < 0.05$) compared to the 0% concentration (10.95 ± 0.90%), as shown in Tables 1–3. These results are similar to those reported by Hartono *et al.* (2022) and Iswanto *et al.* (2013). The particleboards had a MC of less than 10%. The MC and SiO_2 quantity in particleboard result in dimensional stability (Dukarska and Derkowski, 2014; Dukarska *et al.,* 2022; Korai *et al.,* 1999). Putra *et al*. (2022) and Zakaria *et al*. (2021) reported that the D ranged from 650–850 kg/m^3 but was lower than that of particleboard with polyurethane variation ranging from to 825–1,261 kg/m^3 (Masturi *et al*., 2020). According to de Souza *et al*. (2022) and Yang *et al*. (2023), particleboard has a WA value of approximately 30%, and TS ranges from 8.67%–11.74%. Valle *et al.* (2020) reported that particleboards with SiO_2 showed reduced TS and improved dimensional stability without compromising the mechanical properties owing to the superior hydrophobic properties of SiO_2 compared to commercial particleboards (Amali *et al*., 2021; Banciu *et al*., 2023; Meng *et al*., 2020).

Table 1. Moisture content, density, water absorption and thickness swelling of particleboard under different concentrations of SiO_2

Concentration (%)	MC (%)	D (kg/m^3)	WA (%)	TS (%)
5	7.83 ± 5.72	689.92 ± 21.20	30.98 ± 2.94^a	7.73 ± 1.12^a
3	8.60 ± 3.08	688.90 ± 20.61	32.03 ± 1.24^a	8.36 ± 1.07^a
1	8.94 ± 4.75	686.39 ± 22.37	32.42 ± 1.78^a	8.65 ± 1.16^a
0	9.89 ± 1.98	685.12 ± 29.81	38.83 ± 2.89^b	10.95 ± 0.90^b
Average	8.77 ± 3.88^{ns}	687.58 ± 23.50^{ns}	33.57 ± 2.21	8.92 ± 1.06

The letter ns indicates insignificant differences, and different letters (a and b) indicate significant differences between the percentage of moisture content, density, water absorption, and thickness swelling as obtained from ANOVA, $p < 0.05$, followed by Duncan's new multiple range test.
SiO_2: silicone dioxide, MC: moisture content, D: density, WA: water absorption, TS: thickness swelling, ANOVA: analysis of variance.

Table 2. Internal bonding, modulus of rupture and modulus of elasticity of particleboard under different concentrations of SiO_2

Concentration (%)	IB (MPa)	MOR (MPa)	MOE (MPa)
5	0.42 ± 0.02	15.21 ± 0.67	2,335.96 ± 24.53
3	0.42 ± 0.01	15.41 ± 0.44	2,340.74 ± 22.95
1	0.43 ± 0.03	15.57 ± 0.39	2,349.39 ± 17.65
0	0.43 ± 0.02	15.86 ± 0.77	2,374.64 ± 12.65
Average	0.42 ± 0.02^{ns}	15.51 ± 0.57^{ns}	2,350.18 ± 19.42^{ns}

The letter ns indicates an insignificant difference between the percentage of internal bonding, modulus of rupture, and modulus of elasticity, as obtained from ANOVA, $p < 0.05$, followed by Duncan's multiple range test.
SiO_2: silicone dioxide, IB: internal bonding, MOR: modulus of rupture, MOE: modulus of elasticity, ANOVA: analysis of variance.

Table 3. Statistical analysis of moisture content, density, water absorption, thickness swelling, internal bonding, modulus of rupture, and modulus of elasticity

List	Group	Sum of squares	*df*	Mean square	*F*-value	*p*-value
MC	Between group	6.543	3	2.181	0.127	0.941
	Within group	137.181	8	17.148		
	Total	143.724	11			
D	Between group	43.981	3	14.660	0.026	0.994
	Within group	4,527.558	8	565.945		
	Total	4,571.539	11			
WA	Between group	114.293	3	38.098	7.019	0.012
	Within group	43.425	8	5.428		
	Total	157.718	11			
TS	Between group	17.723	3	5.908	5.191	0.028
	Within group	9.104	8	1.138		
	Total	26.827	11			
IB	Between group	0.000	3	0.000	0.243	0.864
	Within group	0.003	8	0.000		
	Total	0.003	11			
MOR	Between group	0.690	3	0.230	0.664	0.597
	Within group	2.774	8	0.347		
	Total	3.464	11			
MOE	Between group	2,670.912	3	890.304	2.229	0.162
	Within group	3,195.653	8	399.457		
	Total	5,866.566	11			

MC: moisture content, D: density, WA: water absorption, TS: thickness swelling, IB: internal bonding, MOR: modulus of rupture, MOE: modulus of elasticity.

3.2. Mechanical properties with the addition of silicone dioxide in particleboard from teak sawdust

The IB of the particleboard was more than 0.4 MPa. The highest IB was found with 0% concentration (0.43 ± 0.02 MPa), followed by 1% concentration (0.43 ± 0.03 MPa), 3% concentration (0.42 ± 0.01 MPa), and 5% concentration (0.42 ± 0.02 MPa); these results were all insignificant ($p < 0.05$). Furthermore, the MOR of particleboard exceeded 14 MPa. The highest MOR was found with 0% concentration (15.86 ± 0.77 MPa), followed by 1% concentration (15.57 ± 0.39 MPa), 3% concentration (15.41 ± 0.44 MPa), and 5% concentration (15.21 ± 0.67 MPa); these values were all insignificant ($p < 0.05$). The MOE of the particleboard exceeded 1,800 MPa. The highest MOE was found with 0% concentration (2,374.64 ± 12.65 MPa), followed by 1% concentration (2,349.39 ± 17.65 MPa), 3% concentration (2,340.74 ± 22.95 MPa), and 5% concentration (2,335.96 ± 24.53 MPa); these values were all insignificant ($p < 0.05$). These results align with those of previous studies by Karlinasari *et al.* (2012) and Semple and Smith (2006), who reported IB values of 0.3–0.5 MPa. The IB strength depends on D (Korai, 2021; Palacios *et al*., 2018). Drovou *et al.* (2019) and Moubarik *et al.* (2010) reported MOR values ranging from to 11–16 MPa and MOE values of approximately 2,225 MPa. The strength value depends on the type and composition in the particleboard (Hrázský and Král, 2003; Kowaluk and Jeżo, 2021; Varanda *et al.,* 2014). Candan and Akbulut (2015) and Karaman *et al.* (2019) reported that the physical and mechanical performance of wood particleboards decreased when SiO_2 was added because the dispersion of the substance had a slight inhibitory effect on strength (Al-Thobity and Gad, 2021; Karim *et al.,* 2020).

4. CONCLUSIONS

The optimal concentration for SiO_2 addition in particleboard from teak sawdust was at 1% concentration to reduce both WA (32.42% ± 1.78%) and thickness swelling (8.65% ± 1.16%). The product at this concentration passed the standard tests of physical and mechanical properties, which reduced the cost of the SiO_2 content for particleboard processing. These results suggest that SiO_2 can resist moisture content but may slightly reduce the strength.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

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