Development of Particleboard from Uprooted Tea (*Camellia sinensis*) Plants

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Abstract

This study was carried out to investigate the suitability of particleboards using uprooted tea plants (*Camellia sinensis*). Wastage and uprooted tea plants were collected from Neptune Tea Garden, Chattogram. The uprooted tea plants were cut into the clipper machine into small portions. Following that, they were processed into chips using a hammer mill machine, which was then dried in a batch oven to the suitable moisture content (5%). Single-layer particleboards were fabricated in a laboratory hot press machine with four different densities i.e. 650, 700, 750 and 800 kg/m³ using liquid urea formaldehyde as an adhesive. Finally the physical and mechanical properties of particleboards made from uprooted tea plants were studied. Characteristics of particleboards such as modulus of rupture (MOR), internal bond strength (IB), water absorption (WA) and thickness swelling (TS) were measured as a part of the experiment. Results show that particleboards made from uprooted tea plants of 800 kg/m³ density had good static bending MOR property (112.00 kg/cm²) and excellent IB strength property (10.04 kg/cm²). The mean MOR value of the 800 kg/m³ density particleboards was above the Indian (IS 3087, 2005) and ANSI (A208.1-1999) standard specifications but lower than the British (BS 5669-2:1989) standard specification. Moreover IB strength value was above the Indian, ANSI and British standard specifications.

সারসংক্ষেপ

উপড়ে ফেলা চা গাছের (*Camellia sinensis*) কুঁচি ব্যবহার করে পার্টিকেল বোর্ড তৈরির উপযুক্ততা যাচাই করার উদ্দেশ্যে এই গবেষণাটি করা হয়। নেপচুন চা বাগান, চট্টগ্রাম থেকে উপড়ে ফেলা চা গাছগুলো সংগ্রহ করা হয়। উপড়ে ফেলা চা গাছগুলোকে প্রথমে ক্লিপার মেশিনের সাহায্যে টুকরা করা হয়। পরে হ্যামার মিল মেশিনের সাহায্যে টুকরাগুলো থেকে চিপস প্রস্তুত করে একটি ব্যাচ ওভেনে উপযুক্ত আর্দ্রতায় (৫%) শুকানো হয়। একটি ল্যাবরেটরি হটপ্রেস মেশিনের সাহায্যে এক স্তরবিশিষ্ট চারটি ভিন্ন ঘনমাত্রার (৬৫০, ৭০০, ৭৫০ এবং ৮০০ কেজি/মি.৩) পার্টিকেল বোর্ড তৈরি করা হয় যেখানে আঠা হিসেবে তরল ইউরিয়া ফরম্যালডিহাইড ব্যবহার করা হয়েছিল। পরিশেষে উপড়ে ফেলা চা গাছ থেকে তৈরিকৃত পার্টিকেল বোর্ডগুলোর ভৌত ও যান্ত্রিক শক্তির বৈশিষ্ট্য নির্ণয় করা হয়। উক্ত গবেষণার অংশ হিসেবে পার্টিকেল বোর্ডগুলোর মডুলাস অব রাপচার (MOR), অভ্যন্তরীণ বন্ধন শক্তি (IB), জল শোষণ ক্ষমতা (WA), পুরুত্বের স্ফিতি (TS) পরিমাপ করা হয়েছিল। ফলাফল বিশ্লেষণে দেখা যায় যে, উপড়ে ফেলা চা গাছ থেকে প্রস্তুতকৃত ৮০০ কেজি/মি.৩ ঘনত্বের পার্টিকেল বোর্ডগুলোর MOR বৈশিষ্ট্য ভাল (১১২.০০ কেজি/সেমি.২) এবং চমৎকার অভ্যন্তরীণ বন্ধন শক্তিবিশিষ্ট (১০.০৪ কেজি/সেমি.২)। ৮০০ কেজি/মি.৩ ঘনত্বের পার্টিকেল বোর্ডগুলোর MOR শক্তির গড় মান ভারতীয় (IS 3087, 2005) এবং এএনএসআই (A208.1-1999) স্ট্যান্ডার্ড মানের উপরে কিন্তু ব্রিটিশ স্ট্যান্ডার্ড (BS 5669-2:1989) মানের চেয়ে নিচে। অন্যদিকে অভ্যন্তরীণ বন্ধন শক্তির (IB) মান ভারতীয়, এএনএসআই এবং ব্রিটিশ স্ট্যান্ডার্ড মানের উপরে।

Key words: Ammonium chloride (NH_4Cl), Particleboards, Uprooted tea plants, Urea formaldehyde (UF),

Introduction

The forest area has declined due to the increasing demand for agricultural land, timber, firewood and other forest produces (ADB 1992). The timber resources have become scarce day by day because of unplanned and irrational resource management including most of the long rotation wood species of which only one-tenth are in great demand for furniture and plywood industries. The vast majority of timber species are utilized. With an expanding local and worldwide demand for tropical timber, there is increased interest in the suitability for commercial purposes of lesser-used tropical timber species as an alternative raw material for forest based industries and to ensure sustainable management of the forest. Through maximum utilization (plywood/ particleboard making), increasing service life and improving the quality of wood, we can conserve more forest resources.

Bangladesh is an important tea-producing country. It is the 10th largest tea producer in the world. Its tea industry dates back to British rule, when the East India Company initiated the tea trade in the hills of the Sylhet region. In addition to that, tea cultivation was introduced to greater Chattogram in 1840. Now Bangladesh has 166 commercial tea estates, including many of the world's largest plantations. The tea industry of Bangladesh accounts for 3% of global tea production and employs more than 4 million people. The global production of tea is about 4,299 million kg produced in about 40 countries in the world (ITC 2013). The average yield of tea (*Camellia sinensis*) in Bangladesh is very low in comparison to other major tea producing countries e.g. India, Sri Lanka and Kenya. One of the main reasons for such yield difference is the length of the harvesting season. Being in the sub-tropics, tea is harvested about 8-9 months per year in Bangladesh, whereas in South India, Sri Lanka and Kenya it is harvested all the year round due to prevailing favorable climatic conditions e.g. day length, temperature and rainfall (De Costa *et al.* 2007). There is a greater tendency for tea shoots to become dormant when the photoperiod is less than 11.16 hours and during the winter it becomes 10.6 hours in Bangladesh (Alam 1999).

In terms of both economics and ecology, it is quite profitable to make particleboard with product residues (Ghalehno *et al.* 2013). Several research works have been carried out on particleboard production from a mixture of waste tea leaves and wood chips (Yalinkilic *et al.* 1998; Batiancela *et al.* 2014; Risnasari *et al.* 2019). The gluing characteristics of many introduced timber or non timber species of Bangladesh are not known. Adequate knowledge of the gluing characteristics is essential for optimum utilization of the resources by the respective industries. It is established a fact that gluability is a function of wood, its structure, presence of extraneous materials etc. No research papers were found related to tea plant particleboards. The study was undertaken in finding out the gluability of the tea plant in the manufacture of particleboards.

Materials and Methods

Raw material collection and processing

Wastage and uprooted tea plants were collected from Neptune Tea Garden, Vujpur, Fotikchori, Chattogram. At first plants were cut into small pieces with a clipper machine and then the small pieces were converted into chips in a hammer mill machine. After that, the chips were dried up to 5% moisture content in a batch oven.

Particleboard manufacturing

Five-single layer particleboards sizes of 500 mm × 500 mm × 12 mm having a target density of 650, 700, 750 and 800 kg/m^3 were made in a laboratory hot press machine. The temperature of the platens of the hot press was maintained at 140°C. In the particleboard preparation liquid UF glue (50% solid content) was used as a binder in which NH_4Cl was mixed as a hardener. The amount of UF glue was 20% based on oven dry chips whereas 2% NH_4Cl was used based on UF glue. After mixing the glue with the chips the mat was formed by hand. Then the mats were pressed in a vertical moving up hydraulic laboratory press machine (160 Ton, Williams-White & Co., USA) primarily at 35.6 kg/cm² for 6 minutes which was then reduced step by step (Table 1). Finally, the boards were conditioned at 65±5% relative humidity and 20±2°C temperature before they were set to tests.

Table 1. Manufacturing process under experimental conditions.

Board thickness	Solid content of UF glue	Proportion of UF glue used	Hot press temperature	Specific Pressure	Pressure time
(mm)	(%)	(%)	(°C)	(kg/cm²)	(min)
12	50	20	140	35.6	6
				10.5	4
				3.5	2

Test sample preparation

After conditioning, the particleboards were cut into various test specimens. The MOR and IB strength tests were carried out according to the specification of IS: 2380 (Anon 1977) in a computerized wood-based panel Universal Testing Machine (Tenson, MWW-10, China). For the determination of TS and WA, Three specimen sizes of 100 mm x 100 mm were taken from each board. The thickness of the specimens was measured with the platform type thickness gauze with an accuracy of 0.01 mm. The test specimens were immersed in 25 mm depth of cold water. Then the test specimens were withdrawn from the water, wiped with a damp cloth, reweighed and re-measured the thickness at two different times (2 hours and 24 hours) as before. After that, the percentage of WA and TS were calculated. The test results were then compared with the standard specifications given in Table 2.

Table 2. Standards specifications for physical and mechanical property of particleboards.

Standards	Board thickness (mm)	Density (kg/m³)	MOR (kg/cm²)	IB (kg/cm²)	TS (%)		WA (%)	
					2hr	24hr	2hr	24hr
IS 3087 (Anon 2005)	6-20	500-900	110.00	8.00	10.00	NA	25.00	50.00
ANSI A208.1 (Anon 1999)			110.00	4.00	NA	8.00	NA	NA
BS 5669-2 (Anon 1989)			138.00	3.40	8.00 (for 1 hour)	NA	NA	NA

NA= not specified in test requirements

Statistical design and analysis

The experiments were carried out in a completely randomized design (CRD) with five replications. Analysis of variance (ANOVA) and least significant difference (LSD) test were carried out to evaluate the significance of differences among the different densities of boards.

Results

Analysis of variance (ANOVA) was used to assess any correlation between boards of different densities. The results showed that the different densities had significant effects as $p \leq 0.05$ on the MOR, IB, TS and WA properties. The mean value of MOR and IB are given in Table 3.

From Table 3, it was found that the MOR values of the particleboards were different for four different densities. Particleboards containing 800 kg/m^3 density had the highest MOR value compared to the other densities (Fig. 1). The value was 112.00 kg/cm^2 which satisfied both the Indian (110.00 kg/cm^2) and ANSI Standards (110.00 kg/cm^2) but not the British standard (138.00 kg/cm^2) specification (Table 2).

Measurements of IB strength properties are presented in Table 3. It was found that the IB values were different for different densities of particleboards. Particleboards containing a density of 800 kg/m^3 had the highest IB strength values among all other densities of particleboards (Fig. 2). The value was 10.04 kg/cm^2 which satisfied the Indian (IS 3087: 2005), ANSI (A208.1: 1999) and British Standard (BS: 5669-2: 1989) specifications.

Table 3. Mechanical properties of particleboards made from uprooted tea plants.

Board thickness	Density kg/m^3	Static bending strength (MOR) kg/cm^2	Internal bond strength (IB) kg/cm^2
12 mm	650	63.54 ± 2.75	8.06 ± 0.11
	700	68.60 ± 1.16	8.31 ± 0.12
	750	87.24 ± 0.60	8.71 ± 0.08
	800	112.00 ± 0.73	10.04 ± 0.14
F-value		1294.94	3006.33
Significant value		4.79E-21	5.02E-25

Note: Mean followed by standard error (± SE)

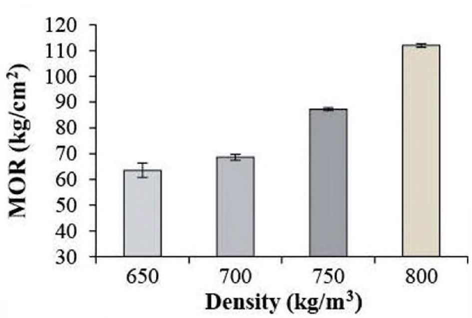

Figure 1. Density vs. MOR

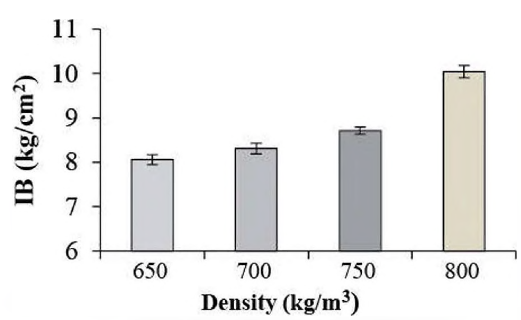

Figure 2. Density vs. IB strength

Table 4. Physical properties of particleboards made from uprooted tea plants.

Board Thickness	Density kg/m³	TS (%)		WA (%)	
		2 hr	24 hr	2 hr	24 hr
12 mm	650	19.34 ± 0.11	23.77 ± 0.22	44.45 ± 1.04	53.28 ± 1.08
	700	19.15 ± 0.12	23.62 ± 0.16	43.79 ± 0.62	51.89 ± 0.67
	750	18.22 ± 0.10	23.19 ± 0.22	42.19 ± 0.34	50.99 ± 0.27
	800	18.12 ± 0.14	21.25 ± 0.24	40.23 ± 0.30	48.04 ± 0.35
F-value		2924.20	2885.87	2712.55	2642.70
Significant value		6.79E-25	7.85E-25	1.54E-24	2.05E-24

Note: Mean followed by standard error (± SE). hr = Hour

The WA and TS properties had been evaluated for different densities of particleboards made from uprooted tea plant chips (Table 4). The test samples were soaked under water for 2 hours and 24 hours, weight and thickness differences were measured for the determination of WA and TS values (Fig. 3, 4, 5 and 6). The observed TS values of the different types of particleboards were 18.12-19.34% after 2 hours and 21.25- 23.77% after 24 hours of water soaking (Table 4).

The WA values of the different types of particleboards made from uprooted tea plants ranged from 40.23-44.45% after 2 hrs and 48.04-53.28% after 24 hrs (Table 4).

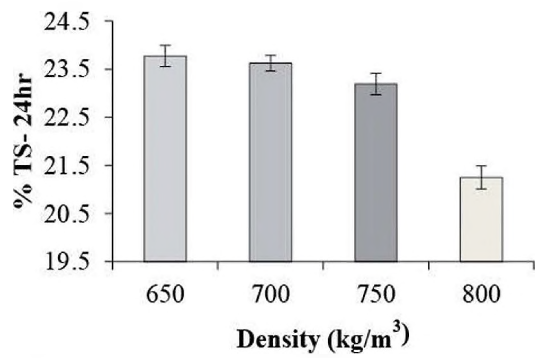

Figure 4. Density vs. thickness swelling for 24 hours

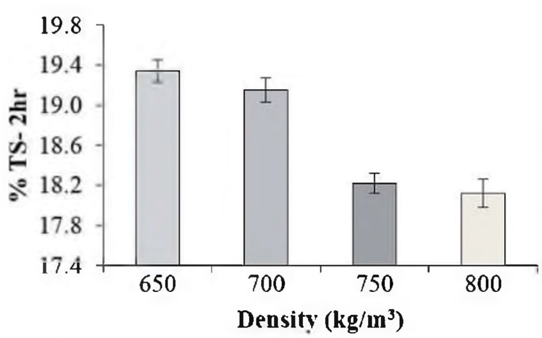

Figure 3. Density vs. thickness swelling for 2 hours

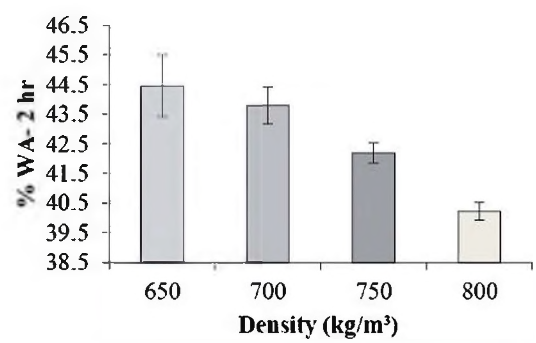

Figure 5. Density vs. water absorption for 2 hours

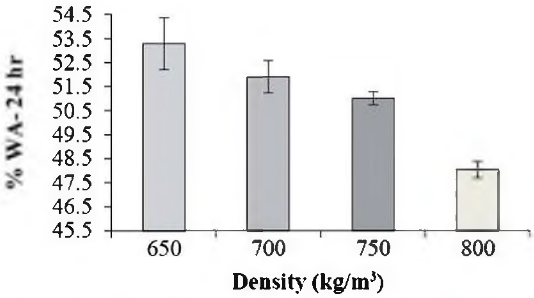

Figure 6. Density vs. water absorption for 24 hours

Discussion

After data analysis, we saw that the MOR value increased with increasing the board density. However, the extent of this growth was not proportional. Particleboards containing a density of 800 kg/m³ had the highest MOR values than the other densities of particleboards. The higher density particleboard makes it stronger and more resistant to breaking when under heavy loads. The density of the board is one of the factors that affect the low or high MOR value. As the MOR value decreases the bond between the boards weakens (Haygreen and Bowyer 1996). According to Kollmann *et al.* (1975), MOR is the most essential mechanical characteristic of particleboards in terms of their use as interior components.

The numerical values of IB strength properties were found different for different densities of particleboards. The result demonstrated that an increase in board density leads to an increase in IB strength. The IB strength is an indicator of resin penetration into the internal structure of any composite board. If the resin does not penetrate well, the internal bond in the center of the medium will be weak and the surfaces will separate easily. The IB test is also used to measure the laminating strength between layers of a composite structure and determine how well they stick to each other (Hutten 2007). The IB strength property gives information about the structure of particleboards, which ensures a fine adhesive property and dimensional stability of the particleboard structure. Risnasari (2019) found that the IB value made from 100% waste tea leaf particleboard was 1.12 kg/cm².

The TS or WA value of particleboards is one of the basic properties that determine whether the panel will be used in dry or humid situations. When particleboard is exposed to water contact, wood chips swell and residual stress that is created during the board pressing process is released, which leads to an increase in the thickness of the panel. The strength characteristics of particleboard are also reduced by both WA and TS properties. From Table 4, it had been observed that the TS and WA of the particleboards decreased with increasing the board density. These growth values were not linear. The TS of the panels is related to the amount of WA, so higher WA contributes to higher swelling in thickness. From the results, it was observed that the mean WA value of 800 kg/m³ particleboard after 24 hours of soaking was 5.78% lower than that of particleboards having 750 kg/m³ densities.

Particleboard is commonly used in the interior for household purposes. Household furniture is kept at a safe distance from water, although accidental water exposure will not reduce the durability of the panel and its properties. Kollmann *et al.* (1975) reported that the highest TS after two hours of immersion in water should not exceed 6-10% of the original thickness. However, the addition of suitable additives may improve the properties of the particleboards. The physical and mechanical properties of the experimental particleboards made from 100% uprooted tea plants are better than the particleboards prepared from a mixture of weste tea leaves and wood chips as indicated by Yalinkilic *et al.* (1998); Batiancela *et al.* (2014); Risnasari *et al.* (2019).

Conclusion

The mechanical strength properties and the dimensional stability of 800 kg/m³ density particleboard made from uprooted tea plants are satisfactory and the board can be used as furniture components. The mechanical strength values indicate stronger bonding. If uprooted tea plants can be used as an alternative source of raw materials for manufacturing particleboards it is possible to protect forest resources through maximum utilization.

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