Suitability of Medium Density Fiberboard Made from Hybrid *Acacia* Wood

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Abstract

This experiment was conducted to evaluate the suitability of medium density fiberboard (MDF) made from hybrid *Acacia* wood fiber as raw material and urea formaldehyde (UF) as resin binder. Single layer fiberboards were fabricated by five different densities e.g. 700, 725, 750, 775 and 800 kg/m³ using hybrid *Acacia* wood fiber. Mechanical and physical properties including modulus of rupture (MOR), internal bond strength (IB), thickness swelling (TS) and water absorption (WA) of the fiberboards were tested according to the Indian Standard (IS 2380:1977). The results of the physical and mechanical properties of the fiber boards were compared with Indian Standard (IS 12406: 2003), Euro Standard (D-6300, 1990) and American National Standards Institute (ANSI) MDF standard (A208.2, 1994). The results showed that the 800 kg/m³ density fiberboards made from hybrid *Acacia* wood had the best MOR value and maximum IB strength characteristics among the others. For 800 kg/m³ density fiberboards the MOR value was above the Indian & ANSI Standard but lower than the Euro Standard; and the IB strength value was above the Indian, Euro & ANSI Standard specifications. Water absorption and thickness swelling properties were used to determine the water resistance of the fiberboards.

সারসংক্ষেপ

হাইব্রিড একাশিয়া কাঠের তন্তু এবং ইউরিয়া ফরম্যালডিহাইড রেজিন দ্বারা তৈরিকৃত মধ্যম ঘনত্বের ফাইবার বোর্ডের (MDF) উপযুক্ততা যাচাইয়ের পরীক্ষা চালানো হয়। হাইব্রিড একাশিয়া কাঠের ফাইবার দ্বারা এক স্তরবিশিষ্ট বিভিন্ন ঘনত্বের ফাইবার বোর্ড তৈরি করা হয় যেমন ৭০০, ৭২৫, ৭৫০, ৭৭৫ এবং ৮০০ কেজি/ঘন মি.। ফাইবার বোর্ডগুলোর ভৌত এবং যান্ত্রিক বৈশিষ্ট্যাবলী ইন্ডিয়ান স্ট্যান্ডার্ড (IS ২৩৮০:১৯৭৭) অনুসারে পরীক্ষিত। ফাইবার বোর্ডগুলোর ভৌত এবং যান্ত্রিক বৈশিষ্ট্যাবলীর পরীক্ষণীয় ফলাফল ইন্ডিয়ান স্ট্যান্ডার্ড (IS ১২৪০৬: ২০০৩), ইউরোপীয় স্ট্যান্ডার্ড (D-৬৩০০, ১৯৯০) এবং ANSI স্ট্যান্ডার্ড (A২০৮.২,১৯৯৪)-এর সাথে তুলনা করা হয়। ফলাফল বিশ্লেষণে দেখা যায় যে, ৮০০ কেজি/ঘন মি. ঘনত্বের ফাইবার বোর্ডগুলোর Modulus of rupture (MOR) এবং Internal bond (IB) শক্তির মান অন্যান্য ঘনত্বের বোর্ডের মানের চেয়ে সর্বোত্তম। ৮০০ কেজি/ঘন মি. ঘনত্বের ফাইবার বোর্ডের MOR শক্তির মান ইন্ডিয়ান এবং ANSI স্ট্যান্ডার্ড মানের উপরে কিন্তু ইউরোপীয় স্ট্যান্ডার্ড মানের নিচে। অন্যদিকে IB শক্তির মান ইন্ডিয়ান, ইউরোপীয় এবং ANSI স্ট্যান্ডার্ড মানের উপরে। ফাইবার বোর্ডের পানি সহ্য করার ক্ষমতা পরিমাপ করার জন্য বোর্ডগুলোর পানি শোষণ ক্ষমতা এবং তাদের পুরুত্বের স্ফীতি পরীক্ষা করা হয়।

Key words: Hybrid *Acacia* wood, Internal bond strength (IB), Medium density fiberboard (MDF), Modulus of rupture (MOR), Urea formaldehyde (UF).

Introduction

Wood composite panels are one of the building materials that are widely used as a raw material in furniture, shelving, cabinet making and other non-load-bearing construction applications. Particleboards and fiberboards, two types of composite panels though often classified together, are usually made with different techniques, materials and are utilized in different conditions.

The utilization of medium density fiberboard (MDF) as an alternative to solid wood is rising day by day. MDF is one of the fastest growing composite products in the global wood-based panel market (Akgul *et al.* 2013). It is an engineered wood product made by breaking down hardwood or softwood residuals into wood fibers, combining it with a resin binder and forming panels by applying high temperature and pressure. MDF is generally denser than plywood and particleboard. It can be used as a building material similar to plywood. MDF is also useable for furniture such as cabinets and household materials like doors, because of its strong surface.

For solid wood warping, cracking and bug infestations are the most common disadvantages. MDF does not get twisted or cracked like wood. It is durable, easier to customize and available in larger sizes than solid wood. MDF is cheaper than solid wood and lasts longer with proper maintenance.

The production of MDF has extensively increased recently and has a major market share in the wood composite industry (Akgul and Camlibel 2008; Evans 1997). The demand for composite wood products, such as plywood, oriented strand board (OSB), hardboard, particleboard, MDF and veneer board products has been recently increased significantly throughout the world (Sellers 2000; Youngquist 1999).

The first MDF was made in 1965 at a particleboard plant in New York. The MDF capacity has increased rapidly around the world. Since the first production in 1965, the world capacity of MDF is now estimated at 36×10^6 m^3 yr^{-1} (Wadsworth 2002). In Iran, the first MDF factory was established in 2004 with an annual capacity of 4×10^4 m^3. MDF production in 2012 has enhanced almost 16 times compared to 2004 (Firouzabadi and Ghorbannezhad 2014).

Hybrid *Acacia* was discovered in road side stands in Malaysia as reported by Pinso and Nasi (1991). It is a fast growing tree species and its basic density is 472 kg/m^3 (Jusoh *et al.* 2014). *Acacia mangium* and *Acacia auriculiformis* can cross-pollinate naturally resulting in hybrid *Acacia* that grows much faster than the parent trees (Tham 1976). About 40 years ago, *A. mangium* and *A. auriculiformis* were introduced in Bangladesh as shade trees in the tea gardens (Banik and Islam 1996). Although this species is used by furniture and plywood industries, information regarding its gluing properties is not adequately known. Adequate knowledge of the gluing characteristics is essential for optimum utilization of this wood resource for the relevant industries. The study was undertaken to find out the suitability of fiberboard made from hybrid *Acacia* wood and its maximum utilization.

Materials and Methods

Materials preparation

Hybrid *Acacia* woods were collected from Kalurghat, Chattogram. The wood was cut into pieces of shorter length. The pieces were hammer milled to chips using screen of 0.60 cm diameter. The chips were then sieved through 20-mesh screen to remove dust and dried in the batch oven at 70ºC temperature to reduce the moisture content to 10%. The chips were cooked by direct steaming at 120ºC temperature in a stainless steel rotary digester of 0.02 m³ capacity under 10 kg/cm² digester pressures for one hour. They were then refined in a single-rotating disk attrition mill to get fiber from each cooking. The fibers were oven-dried at 3-4% moisture content before the panel formation.

$$(\%)\ \text{Moisture content} = \frac{Original\ weight - Oven\ dry\ weight}{Oven\ dry\ weight} \times 100 \qquad (1)$$

Manufacture of fiberboard

Since the MDF panels usually have a density of 600-900 kg/m³ (IS: 12406, 2003), it was randomly selected five densities within this range. Five single layer MDF boards were prepared under five treatments (e.g. T_1 = 700, T_2 = 725, T_3 = 750, T_4 = 775 and T_5 = 800 kg/m³) in the laboratory hot press machine using hybrid *Acacia* wood fiber. The dimensions of the fiberboards were 50 cm × 50 cm × 1.25 cm having the target density. The temperature of the platens of the hot press was maintained at 160-170ºC. Twenty percent (20%) liquid UF glue based on oven dry fiber was used in the fiberboard preparation. The liquid UF glue was catalyzed with 2% NH_4Cl (ammonium chloride). A fiber mat board was formed and pre-pressed manually in wooden fabricated bordered frame. After that the mat was pressed initially for 6 minutes in the hot press machine. This pressure was then lowered in two steps firstly for 4 minutes and then an additional of 2 minutes. Finally the fiberboards were conditioned at 65 ± 5% relative humidity and 20 ± 2ºC temperature before they were put to tests. The overall conditions for making fiberboards are given in Table 1.

Table 1. Experimental conditions for manufacturing of fiberboards.

Board thickness (mm)	Solid content of UF (%)	Mat moisture (%)	Press temperature (º C)	Specific pressure (psi)	Pressure time (min)	Density (kg/m³)
12	50	11-12	160-170	500	6	700-800
				150	4	
				50	2	

Test samples preparation

The fiberboards were cut into various test samples to determine the MOR, IB, WA and TS properties according to IS: 2380 (Anon. 1977) specification. The performance of fiberboards was evaluated by its mechanical and physical properties which were later compared with the standard results shown in Table 2.

Modulus of rupture (MOR)

The bending strength MOR was carried out in a Riehle screw power type universal testing machine (UTM) according to the IS: 2380 (Anon. 1977) specification. Specimen sizes of 35 cm × 7.50 cm × 1.25 cm are tested on a 30 cm span with center loading. The test parameters of modulus of rupture are as follows.

The modulus of rupture, *MOR* (eqn.2) can be found by substituting the maximum load, P for the load at the proportional limit.

$$MOR = \frac{3Pl}{2bh^2} \quad (2)$$

Where, MOR = modulus of rupture in kg/cm^2
P = maximum load in kg
l = length of span in cm
b = width of the test specimen in cm
h = depth of the test specimen in cm

Internal bond strength (IB)

The IB strength test was also performed using the UTM with the specification of IS: 2380 (Anon. 1977). In this case, wooden blocks of 75 mm × 50 mm × 25 mm were glued through cold press with the test specimens. Hence the urea formaldehyde glue catalyzed with 4% hardener (NH_4Cl) was used.

The internal bond (IB) strength in kg/cm^2:

$$IB = \frac{P}{A} \quad (3)$$

Where, P = maximum load in kg
A= area of the test specimen in cm^2

Water absorption (WA)

Water absorption due to general absorption of water was done using the specimens of 100 mm × 100 mm soaked in 25 mm depth of cold water (25±2^{0}C) for 24 hours. For this experiment, three specimens were taken from each board.

$$\text{WA (\%)} = \frac{increase\ of\ weight\ with\ water}{Ovendry\ weight} \times 100 \quad \text{.......... (4)}$$

Thickness swelling (TS)

The samples, tested for WA measurement, were used to determine TS with the platform type thickness gauze with an accuracy of 0.01 mm.

$$\text{TS (\%)} = \frac{increase\ in\ dimension\ or\ volume}{original\ dimension\ or\ volume} \times 100 \quad \text{.......... (5)}$$

At the end of 24 hours, the test specimens were withdrawn from water, wiped with a damp cloth, reweighed and re-measured the thickness as before. The percentage of WA and TS were then calculated. The test results were then compared with the standards given in Table 2.

Statistical design of experiment and analysis

The experiments were carried out in a completely randomized design (CRD) with 5 replications. SPSS statistical software was used for the data analysis. 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.

Table 2. Some standards specifications for physical and mechanical property of MDF Boards.

Specification of some standards	Board thickness (mm)	Board density (kg/m^3)	MOR (kg/cm^2)	IB (kg/cm^2)	TS (%)	WA (%)
					24 hrs	24 hrs
Indian Standard (IS 12406, 2003)	6-20	600 - 900	250.00	8.00	7	30
Euro Standard (D-6300, 1990)	12		350.00	6.50	15	NA
ANSI Standard (A208.2, 1994)	6-19		240.00	6.00	NA	NA

NA= not specified in test requirements.

Results

Analysis of variance was used to assess any correlation between boards of different densities. The results of ANOVA showed that the effects of different densities have significant effects at $p \leq 0.01$ towards the MOR, TS and WA properties. The IB strength value is not significant compare to other parameters at $p \geq 0.01$. The mean value according to least significant difference of MOR, IB, TS and WA were given in Table 3.

Table 3. Mechanical and physical properties of MDF boards made from Hybrid *Acacia* wood.

Type of fiberboard	Board density (kg/m^3)	MOR (kg/cm^2)	IB (kg/cm^2)	TS (%)	WA (%)
				24 hrs	24 hrs
Single layer	700	200 ± 19.24	5.60 ± 0.06	18.08 ± 0.03	38.45 ± 0.02
	725	220 ± 9.35	5.72 ± 0.08	17.21 ± 0.04	35.68 ± 0.04
	750	225 ± 7.91	5.85 ± 0.04	16.65 ± 0.04	33.62 ± 0.07
	775	248 ±6.28	6.40 ± 0.08	16.35 ± 0.04	33.25 ± 0.04
	800	252 ± 5.87	8.10 ± 0.34	12.67 ± 0.03	28.72 ± 0.07
F-value		25.20	1.05	8.23	1092.50
Significant value		1.89E-04	0.11250	0.003018	2.39E-10

Mean ± SD (Standard deviation)

From the Table 3, it was found that the MOR values of the fiberboards were different for five different densities. Fiberboards containing 800 kg/m³ density was the highest MOR value compared to the other densities (Fig. 1). The MOR value of 800 kg/m³ fiberboard was 252.00 kg/cm² which satisfied the Indian Standard (250.00 kg/cm²) and ANSI Standard (240.00 kg/cm²) but did not meet the Euro Standard (350.00 kg/cm²) specification.

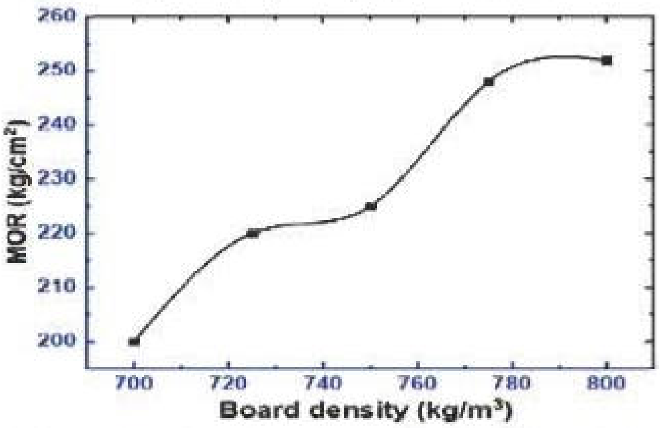

Figure 1. Modulus of rupture (MOR) of the fiberboards.

The internal bond (IB) strength value of 800 kg/m³ density fiberboard was higher than that of other densities (Fig. 2). Fiberboards made from 775 kg/m³ density met the requirements of ANSI Standard (6.00 kg/cm²) and nearest to the Euro Standard (6.50kg/cm²). Whereas IB strength value of 800 kg/m³ density fiberboard (8.10 kg/cm²) met the requirements of Indian (8.00 kg/cm²), Euro (6.50 kg/cm²) and ANSI Standard (6.00 kg/cm²) specification.

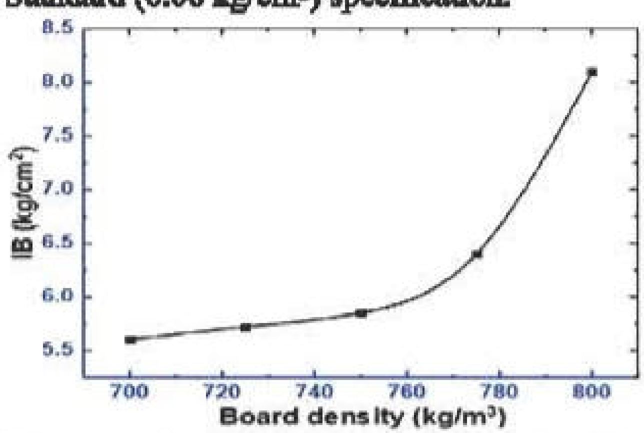

Figure 2. Internal bond strength (IB) of the fiberboards.

The WA and TS properties had been determined for different densities of fiberboards made from hybrid *Acacia* wood fiber. The test samples were soaked under water for 24 hours, weight and thickness differences

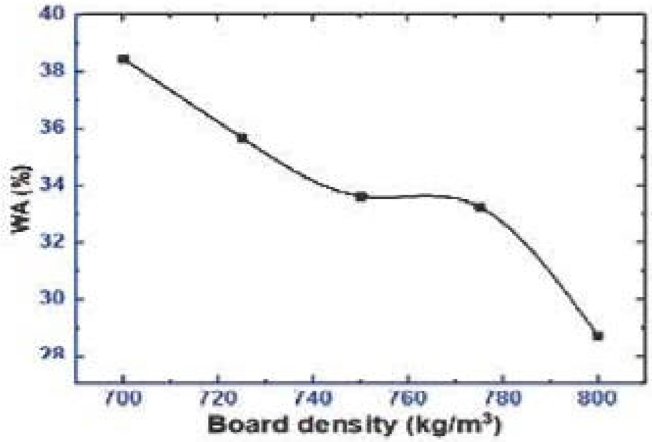

Figure 3. Water absorption (WA) of the fiberboards.

were measured for the determination of WA and TS (Fig. 3 and 4). The observed TS values of the different types of fiberboards were 18.08 to 12.67% after 24 hours of water soaking.

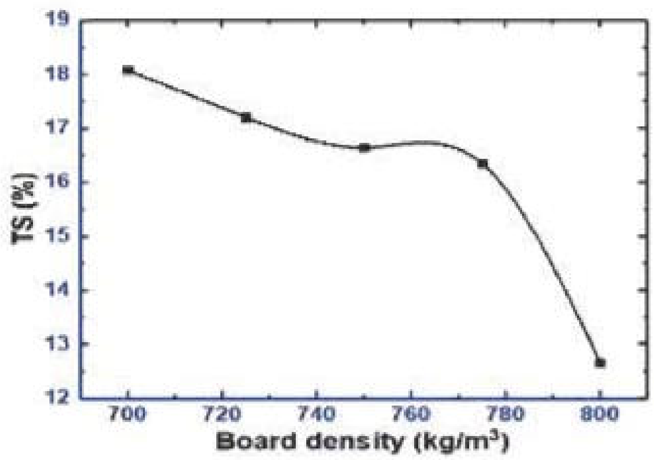

Figure 4. Thickness swelling (TS) of the fiberboards.

Discussion

After data analysis, it was observed that the MOR value was increased with increasing the panel density. However, the extent of this growth was not proportional. Fiberboards containing a density of 800 kg/m³ was the highest

MOR values than the others. There was a significant difference between boards of different densities at 1% level (Table 3). The higher density MDF made it stronger and more resistant to break when under heavy loads. Kollmann *et al.* (1975) pointed out that MOR was the most important mechanical property of particleboards with respect to their particle application as structural elements.

The numerical values of IB strength properties were found different for different densities of fiberboards. These values were found to affect in a similar fashion with a variation of board density. The result demonstrated that an increase in board density leads to an increase in IB strength. This was not significant at 1% level (Table 3). The IB strength property gave information about the structure of MDF, which ensured a fine adhesive property and a good dimensional stability on the fiberboard structure.

The TS is one of the basic properties that determine whether the panel will be used in dry or humid situation. When MDF is exposed to water contact, wood fibers swell and residual stress that is created during the MDF pressing process is released, which leads to an increase in the thickness of the panel (Ayrilmis *et al.* 2009). The strength characteristics of MDF panels are also reduced by both WA and TS properties (Ayrilmis *et al.* 2011). From the Table 3, it has been observed that, the TS and WA of the fiberboards decreased with increasing the panel density. These growth values were not proportional. The average value of TS of all densities fiberboard was close to the Euro Standard but did not meet the Indian Standard requirements. The TS and WA values are significant at 1% level (Table 3).

The TS of the boards is related to the amount of water absorption, so higher water absorption contributes to higher swelling in thickness. According to IS 12406 (Anon. 2003) specification, the absorption of water by standard fiberboard is 30% for 24 hours of soaking and the percentage of TS of the standard board is 7% after the same time interval. From the results, it is observed that the mean WA of 800 kg/m^3 fiberboard after 24 hours of soaking was lower (28.72%) than that of other densities. For WA analysis, considering all only 800 kg/m^3 fiberboards satisfied the IS 12406 (Anon. 2003) specification requirement (30%).

After 24 hours of water soaking, a value of TS below 12% guarantees the dimensional stability of MDF when it is used as a material for interior application and furniture production (Popovska *et al.* 2012). MDF boards commonly used in the interior for household purposes. Household furniture 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 fiberboards.

Conclusion

The test results revealed that the higher MOR values were obtained from the denser panels of MDF made from hybrid *Acacia* wood. In this experiment, almost 80% of fibers yield was found from hybrid *Acacia* wood on the oven-dry weight basis. The fiberboards prepared with a density of 800 kg/m^3 hybrid *Acacia* wood fiber had the most suitable values for the MOR, TS & WA parameters compared to other densities. However, the fiberboards e.g. 700, 725, 750 and 775 kg/m^3 made from hybrid *Acacia* wood can also be used conventionally for household purposes. It can be concluded that hybrid *Acacia* wood was much suitable for the production of MDF at density of 800 kg/m^3.

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