THE PERFORMANCE OF CORN AND COTTON STALKS FOR MEDIUM DENSITY FIBERBOARD PRODUCTION

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Severe shortage of suitable wood for Medium Density Fiberboard (MDF) production makes it necessary to consider using uncommon and non-conventional raw materials such as agricultural residues. In order to demonstrate the suitability and the potential of two agricultural residues (cotton and corn stalks), laboratory MDF boards were produced. Three press temperatures (170, 180 and 190 ºC) were used. Test samples were prepared from the boards after conditioning at 65% RH and 21 ºC, and all tests were performed according to relevant EN standard methods. The results indicated that the MOR and MOE of boards produced from corn stalks were higher than those from cotton stalks, by almost 25%. However significant difference was not observed for internal bonds of boards. Thickness swelling of MDF boards from corn stalks was lower than cotton stalks. Comparing the results obtained with the strength of boards produced from hardwoods showed similarity between corn stalks and wood, but the strength of MDF boards from cotton stalks was lower. However, the results almost satisfied the EN 622-5;1997 requirement.

Keyword: Medium density fiberboard; Corn stalk; Cotton stalk; Press temperature; Strength

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INTRODUCTION

Successful development and application of particleboard during the 1940s and 1950s initiated interest in such products in the wood industry sector by both producers and consumers. Although the intention of manufacturers during this initiation period was the utilization of low quality, and unutilized wood processing and forest operation residues, the initial work helped the development of other panel products (Jahan Latibari and Roohnia 2010). Oriented Strand Board (OSB) and waferboard were developed in North America as a substitute for exterior plywood, utilizing lower grade, small diameter logs from hardwood (aspen) and softwood. However, medium density fiberboard (MDF), which was developed during the 1970s, has been the most successful substitute for particleboard, thanks to its unique properties, including strength, homogeneity, and machining performance (Halvarsson et al. 2008). Such unique specifications opened its way into various applications and generated interest among different consumer sectors, especially cabinet and home furniture. The furniture industry by far is the prime consumer of MDF. However, MDF frequently replaces solid wood, plywood, and of course particleboard in many furniture applications. End users are willing to pay a higher price for MDF. High price and excellent return on investment enabled MDF producers to utilize prime quality raw material to fulfill the requirements of the product and respond to consumer needs very well to their satisfaction. As a result, world MDF production was raised to almost 55.8 million cubic meters in 2009 (FAO 2010).

Interest in MDF production and consumption is not limited to industrial countries, and other regions are not exempt to such developments. Countries like China and Turkey have been able to expand their MDF production at very fast rates compared to more fully industrialized countries. In 2009, China and Turkey produced 27.4 million m^3 and 2.29 million m^3 MDF, respectively, compared to almost 3.8 million m^3 in North America and 3.4 million m^3 in Germany (FAO 2010).

Businesspeople in Iran have looked on MDF as luxury item, and its consumption has experienced a sharp increase (Table 1).

Table 1. MDF Consumption and Production in Iran (m^3)

Year	1996*	1997	1998	1999	2000	2001
Consumption	135	464	6562	9407	21764	44802
Production	-	-	-	-	-	-
Per Capita**	-	0.01	0.11	0.15	0.34	0.6 9

Year	2002	2003	2004	2005	2006	2007
Consumption	63680	140035	243381	300197	399543	577627
Production	-	-	63680	40226	48219	104297
Per Capita**	0.96	2.09	3.58	4.35	5.7	8.12

*: Iran's calendar year starts on March, 21, 1996, which means that the year is from March, 21, 1996 to March, 21, 1997.
**: (m^3/1000); Data were provided by Iran Panelboard Producers Association

Raw material (wood and binder) and energy have been the primary determinants in MDF production cost, and because of these factors, MDF production no longer holds the possibility of utilizing prime quality raw material such as sawmill residues and small logs. The paper industry has been the winner of this competition, and currently good-quality chips are directed towards the paper industry. Therefore MDF production ought to depend on lower quality raw material. In an era in which countries around the world desire to develop and implement local capacities for MDF production, the situation for MDF raw material supply is becoming tense due to declining availability of raw materials. Fast growth, small diameter poplar and eucalyptus wood were the first candidates (Roffael, et al. 1992). Bamboo was investigated, and promising results were reached (Wu-Zhang et al. 2000) and forest-deficient countries like Iran and Egypt had implemented MDF projects based on bagasse (Faraji 1998). Fortunately, unlike some previous attempts in China, Thailand, and Pakistan, these projects have reached successful production. Attempts to utilize the potential of agro-based raw material in panel board production such as particleboard and MDF is still continuing, and an excellent wealth of research and development reports has become available (Akgul and Toslughu 2008; Copur et al. 2008; Lee et al. 2006; Ye et al. 2007; Halvarsson et al. 2010; Pan, et al. 2010; Ciannamea et al. 2010).

Despite the fact that some fiber-deficient countries are operating MDF production facilities or intend to implement such operation, due to declining availability and limitation in wood supply and other fiber sources directed toward MDF manufacturing, attention must be concentrated on uncommon and unconventional fiber supplies, with particular attention to agricultural residues. One such material can be corn biomass, and in particular corn stalks. Some of the countries that suffer from the shortage of wood supply have plans to expand their crop production. These activities generate huge volumes of residues that are not suitable as cattle feed (utilizing cereal straw as cattle feed is practiced by countries in arid zones), and it is not chopped to be left in the fields but only occasionally burned in the fields). The availability of agricultural residues in rural regions and limitations on fiber supply motivate the present investigation to identify its suitability for MDF production.

EXPERIMENTAL

Raw Material

Stalks were harvested from cultivation fields, and leaves and debris were separated and then transferred to Wood and Paper Research Laboratory at Research Institute of Forests and Rangelands located in Karadj, Iran.

Urea-formaldehyde resin at 63% solids, specific gravity 1.26 g/cm^3, viscosity 69 seconds, gel time 81 seconds, and a pH of 8.15 was supplied by a local resin manufacturing plant (Subranko Resins Co.).

Reagent grade ammonium chloride (20% solution) was used as hardener.

Fiber Preparation

Stalks were manually depithed (if needed) and then chipped using a laboratory drum chipper, (Pallmann PHT 120x430). Chips were stored in polyethylene bags until used. The moisture content of chips prior to steaming was about 7%. Chips were steamed at 170ºC for 10 minutes using saturated steam in a laboratory steaming vessel. At the end of steaming period, softened chips were discharged into a closed container and defibered at atmospheric pressure immediately. A laboratory single disc refiner (Faravari Ghomes Co.) with the disc diameter of 25 cm and disc rotation of 1450 rpm was used, and defiberation was performed in three passes.

A laboratory rotating drum dryer (Faravari Ghomes Co.) equipped with electrical heating elements was used for final drying of fiber to reach the final moisture content of 3% (dry basis). Dry fibers were stored in polyethylene bags until used.

The pH and both acid and alkaline buffering capacity of fibers were measured using the procedure introduced by Johns and Niazi (1980).

Fiber Classification

Both corn and cotton stalk fibers were classified using US standard series of 5, 10, 18, 40, 50, and 70 mesh sieves. The fibers were classified for five minutes, and the weight of each fraction was determined and the percentages were calculated.

Board Making and Evaluation

Fibers were blended with 10% resin (dry basis) and 1% hardener (based on dry weight of resin) utilizing a rotary drum blender equipped with a spray nozzle. Minor agglomeration of fibers, especially from cotton stalks, was present. A pre-weighed amount of resinated fibers was then hand formed, simulating industrial forming, using a 400 mm x 400 mm wooden frame. Board target density and thickness were selected at 0.75 g/cm^3 and 10 millimeters. Mats were cold-pressed and then hot-pressed to 10 millimeter final thickness, using a laboratory hydraulic press (Buerkle L100) applying 30 bar specific pressure and five millimeters per second closing speed. Three press temperatures of 170, 180, and 190 ºC and four minutes press time were applied. At the end of the press cycle, boards were discharged and cooled at room temperature. Three boards for each combination of variables and a total of 27 boards were produced.

Test sample were prepared from each board according to EN325-1 standards. Modulus of rupture (MOR) and modulus of elasticity (MOE) were measured according to EN310/1996, Internal bonding (IB), EN319/1996, and for dimensional changes, EN 317/1996 standards.

Statistical Analysis

Factorial experimental design in a completely randomized block was used for statistical analysis of the generated data. In cases where significant difference at either 1% or 5% level was observed, the Duncan Multiple Range Test (DMRT) mean separation of averages was applied. Statistical analysis for social sciences (SPSS) package was used for analysis.

RESULTS AND DISCUSSION

The strength of MDF as a fiber network is influenced by both fiber geometry and the chemical composition of the raw material. Longer fibers produce stronger board. The other factor that influences the strength of the MDF board is the inherent strength of the fibers, which is influenced by its species. In this respect, fibers from agro-based material are usually weak. The average dimensions of fibers from corn and cotton stalks and different hardwoods usually destined for MDF production have been measured and compared (Tables 2). Even though corn and cotton stalks stem fibers are shorter than hardwood fibers, their diameter is smaller than that of hardwoods such as hornbeam and alder (Table 2).

Table 2. The Fiber Length and Diameter of Corn and Cotton Stalks and some Common Woods Used for MDF Production in Iran

Raw material	Fiber length (mm)	Fiber diameter (µm)
Corn stalk	0.936	18.46
Cotton stalk (pith)	0.830	25
Cotton stalk (stem)	1.007	18.55
Poplar	1.08	21.2
Hornbeam	1.46	27
Beech	1.01	18.6
Alder	1.24	29
Wheat straw*	0.9-1.02	25.4-27

* Halvarsson, et al. 2008, 2010

The cellulose content of corn and cotton stalks (measured according to TAPPI Method T264-om-88) were determined as 49.7% and 53.5%, respectively. The relevant values for lignin (measured according to TAPPI Method T222-om-97) were 21.9% and 27.1%.

The UF resin reaction is initiated and propagated in an acid condition that either originates from fibers themselves or by the addition of acid-generating chemicals called hardeners. The pH of wood-based fiber furnish is usually below 6 and in the range of 3.5-5.5 (Halvarsson et al. 2010). Therefore the curing rate of the UF resin in wood-based MDF manufacturing is not a problem, because of appropriate pH as well as acid buffering capacity (Xing et al. 2006). Even though wheat and cereal straw fibers show pH values above 7 and higher acid buffering capacity (Halvarsson et al. 2010), both pH and acid buffering capacity of corn and cotton stalk fibers were lower (Table 3), which do not provide a favorable curing condition for UF resin. Therefore, lower hardener dosage must be foreseen in resin preparation.

Table 3. pH and Buffering Capacity of Corn and Cotton Stalks Fibers Compared with Hardwood Fibers

Material	pH	Acid buffering capacity mL 0.1 N NaOH/g fiber	Alkaline buffering capacity mL 0.1 N H_2SO_4/g fiber
Corn stalks	5.89	0.855	2.25
Cotton stalks	4.74	1.17	1.6
Hardwoods	5.06	2.05	0.07
Wheat straw*	7.5	-	3-3.75

* Halvarsson, et al. 2010

The bending strength, modulus of elasticity, internal bonding, and thickness swelling after 2 and 24 hours immersion in water for MDF boards produced from either corn or cotton stalks applying different press temperatures are summarized in Table 3. Each value in Table 4 is the average of 12 measurements (three replicate boards for each combination of variables and four sets of samples from each board).

In order to reveal the statistical differences among the measured values, statistical analysis was carried out, and the results are summarized in Table 5. The effect of raw material (fiber type) on bending properties and thickness swelling of the boards was significant at the 1% level. Even though the effect of press temperature on bending properties and thickness swelling was not significant, its effect on IB showed significance at the 1% level. This finding indicates that boards produced from corn stalks fibers at 180 ºC press temperature are superior because, when 180ºC press temperature is used, sufficient heat is transferred into the fiber mat placed inside the press and as a consequence of such heat transfer, the core part of the mat receives sufficient heat needed for resin curing, and bonding development is completed. Then IB improves. However, in case of cotton stalks, 190 ºC press temperature was better than other press temperatures, possibily due to higher lignin content and courser fibers (Table 6).

Table 4. Manufacturing Variables and Properties of MDF from Corn and Cotton Stalks

Raw material	Press temperature °C	MOR MPa	MOE MPa	IB MPa	T.S.2 (%)	T.S.24 (%)
Corn stalk	170	22.26	1886	0.415	17.39	25.21
	180	22.16	1950	0.523	15.53	23.48
	190	22.10	1794	0.475	16.57	25.55
Cotton stalk	170	17.64	1546	0.438	26.64	31.37
	180	17.61	1494	0.640	24.06	32.38
	190	22.40	1896	0.482	20.30	29.55

Table 5. Analysis of Variance of the Results of the Measurements

Source	Degrees of Freedom	F Values				
		MOR	MOE	IB	T.S.2	T.S.24
Fiber Type	1	8.754**	8.344**	2.423 n.s	70.808**	48.668**
Press Temperature	2	2.369 n.s	1.132 n.s	8.297**	3.713 n.s	0.219 n.s
Fiber Type & Press Temperature	2	2.600 n.s	4.556*	1.162 n.s	3.457 n.s	2.414 n.s

**: Significant at 1% *: Significant at 5% n.s Non Significant

Results revealed lower MOR values for boards produced from cotton stalks compared to corn stalks (Table 4), when press temperature of 170 or 180°C was used, but the MOR of cotton stalks boards pressed at 190 °C was almost similar. It was expected to observe such low values because of the inherent properties of cotton stalk fibers. The strength of board produced from corn stalks was higher than wood as well (Fig. 2). Cotton stalk contains high level of lignin, and its average fiber length (average of pith and stem) is shorter than corn stalk, which contributes to lower strength values. Furthermore, both fibers are weak, which reduces the overall strength of any product from such raw material.

Figure 1 shows the representative fiber elements in corn stalk. Generally, annual plants material such as straws and stalks (corn and cotton) are less homogenous than even hardwoods. Annual plants contain relatively larger number of cells. In addition to fibers, parenchyma cells, vessel elements, and epidermal cells are present (Han et al. 2001; Halvarsson et al. 2008). Corn stalks contain pith, which is mostly parenchyma cells and contribute to inhomogeneity of elements (Fig. 1). This complicated cell composition is an effective factor to reduce the strength properties of agro-based MDF.

In addition, fiber classification of corn and cotton stalks indicates that small particles are easily created, and the portion of fine particles (dust) is higher than what is considered as typical, but almost identical to mixed hardwood fibers produced during industrial scale defibration (Table 6). We have noticed that defibration of steamed cotton stalks was not as uniform as for corn stalks, wheat straw, or wood chips, and fiber bundles were formed. This behavior makes MDF mat forming very difficult. This type of fiber classification and generation of small particles (dust) is common to other agro-based materials (Lee et al. 2008).

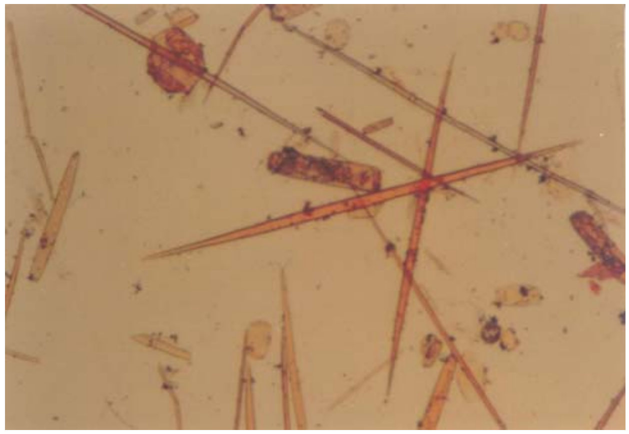

Figure 1. Photograph of the cell wall elements in corn stalk

Table 5. Fiber Classification of Defibered Corn and Cotton Stalks Compared with Mixed Hardwoods

	Sieve Hole Size (mesh)						
Raw material	R5[1] (4mm)	R10 (2mm)	R18 (1mm)	R40 (0.415mm)	R50 (0.300mm)	R70 (0.212mm)	P70 [2] (0.212mm)
Corn stalks	0	20.87	11.63	20.58	17.49	12.42	17
Cotton stalks	0	34.10	12.46	18.60	16.07	10.07	8.7
Bagasse[3]	3.34	16.77	20.97	21.63	12.58	17.21	7.5
Mixed hardwood[3]	3.3	12.67	22.27	20.25	12.23	12.28	26.5
Wheat straw [4]	23			24			

1-Retained 2- Passed 3- Industrial defibration, measured 4- Pilot plant defibration

The Status of Stalks as Raw Material for MDF

A comparison between the properties of MDF boards produced using corn and cotton stalk with board produced from different wood species (common raw material for MDF production) is provided in Figs. 2 to 4 (all boards having been produced applying identical manufacturing conditions to reveal the differences between these material). The results show that the strength of MDF boards from agro-based materials was comparable with wood, and the IB of boards produced from cotton stalks was higher than some woods.

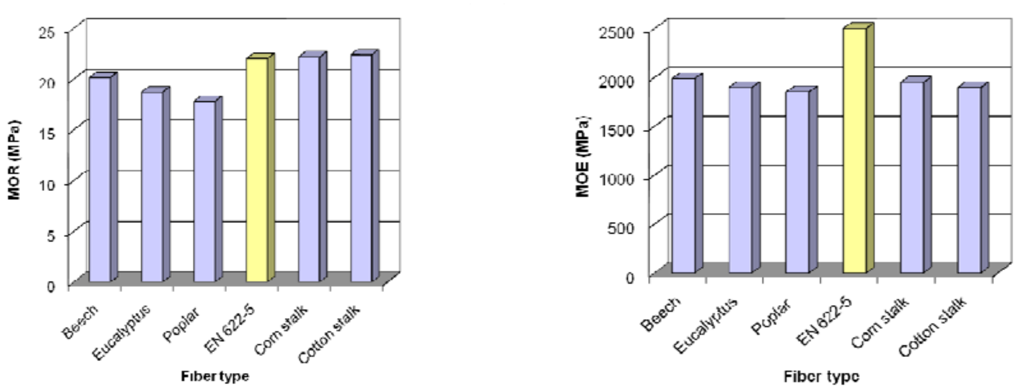

Fig. 2. Illustration of the comparison between the MOR and MOE of the MDF boards produced from different raw material

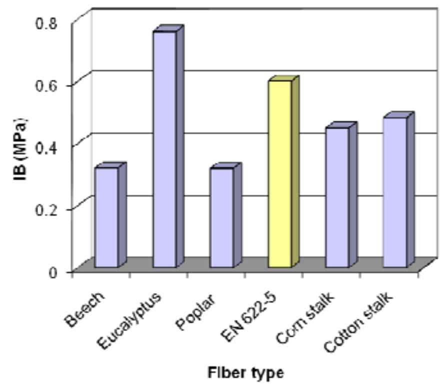

Fig. 3. Illustration of the comparison between the IB of the MDF boards produced from different raw material

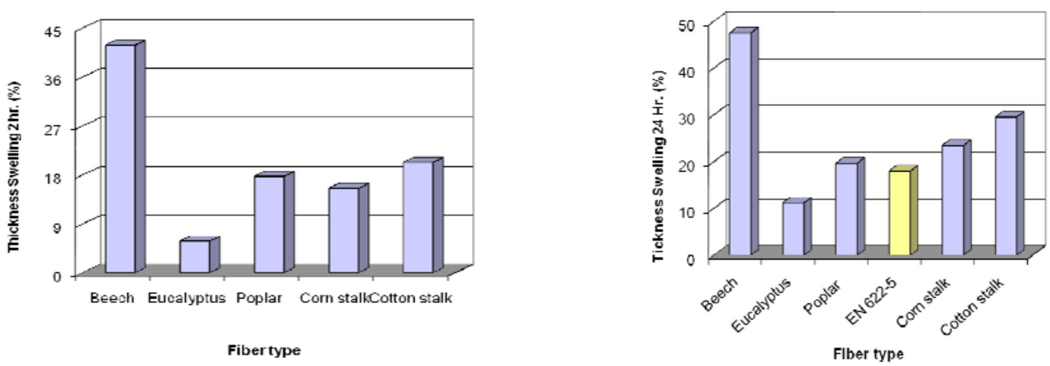

Fig. 4. Illustration of the 2 and 24 hours thickness swelling of the boards produced from different raw material

Even though the strength of MDF from uncommon raw material such as corn and cotton stalk is not comparable with softwoods due to shorter and heterogeneous elements, these materials can be utilized as supplementary raw material in fiber-deficient countries. Comparing the results of this study with similar experiments demonstrates the superiority of corn stalk compared to cotton stalk as well as eucalyptus and poplar wood. Corn stalk yielded MDF with better properties than either eucalyptus or poplar wood. MOR and MOE, as well as IB, were higher than the each of the investigated wood types except *E. camaldulensis*, which is probably the consequence of more flexible fibers from stalks. It was expected that corn stalk fibers, due to their open structure and higher content of hemicelluloses, would demonstrate higher affinity toward water, and show higher thickness swelling, but the thickness swelling of corn stalk MDF was also lower.

The strength values of MDF from agro-based material is low, but can be improved to higher values than EN622-5; 1997 or other standards requirements by applying the following measures: 1- higher dosages of resin (Ye et al. 2007; Halvarsson et al. 2008), 2- unconventional resins such as isocyanates (Copur et al. 2008; Halvarsson et al. 2008), and/or 3- higher densities in the range of up to 850 kg/m^3 (Akgul and Tozluoglu 2008).

CONCLUSIONS

1- World is facing a shortage of wood supply, and the situation in countries located in forest-deficient areas where board production facilities are operating is severe. The situation will become harder in an era in which forest-rich countries are intending to use wood and other lignocellulosic residues for energy. This indicates the need to search for alternative and unconventional fiber supplies. One such lignocellulosic material is stalks that are left unused after crop production.

2- MDF production utilizing corn and cotton stalks revealed that both strength and thickness swelling of these boards can be at an acceptable level. MDF boards produced using corn stalks and applying 10% urea formaldehyde resin and pressed at 180ºC exhibited proper strength values such as 22.16 MPa., 1950 MPa, and 0.523 MPa for MOR, MOE, and IB, respectively. The corresponding values for cotton stalks were 17.61 MPa,1494 MPa, and 0.640 MPa for MOR, MOE, and IB. Thickness swelling after 2 and 24 hours soaking in water were 15.53% and 23.42% for MDF boards from corn stalks and 24.06% and 32.38 % for MDF boards from cotton stalks, respectively.

3- The present study indicates that corn and cotton stalks can be utilized as supplementary raw material for MDF production in fiber deficient regions. To improve the performance of the produced boards, it is advisable to apply higher dosages of UF resin (Ye et al. 2007), higher density, or even thermal treatment of the produced boards (Pan et al. 2010; Halvarsson et al. 2008; Hervillard et al. 2007).

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