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Original Article

Properties of commercial fiberboard from *Sesbania aculeate* and *Tamarix aphylla*

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Abstract

This study determined the properties of 3.2 mm Medium Density Fiberboard (MDF) from a commercial production line. The mixture of fibers from *Sesbania aculeate* (80%) and *Tamarix aphylla* (20%) was bound with urea formaldehyde for laboratory testing. Effects of production line speed, fiber moisture content, and production shift on board properties were assessed. Physical and mechanical properties of the panels were determined according to European standards. This study showed that the production of MDF during the evening shift was ideal, with a line speed of 6.00 m/min and fiber moisture content of 8.70 %, compared to morning and night shifts. The production line speed, fiber moisture content, and operation shift affected the properties of MDF boards but met the minimum requirements in the standards. The mix of fibers is a viable combination for commercial production.

Keywords: *Sesbania aculeate*, *Tamarix aphylla*, fiberboard, moisture content

1. Introduction

Fiberboard is a fibrous and homogeneous panel made of lignocellulosic fibers. The density determines the type of fiberboard, with density from 0.50 to 0.80 kg/m^3 characterizing medium density fiberboard (MDF), and density greater than 0.80 characterizing hardboard (Gul, Khan & Shakoor, 2017). Medium density fiberboard is a wood-based composite produced by bonding wood fibers with a binder under elevated temperature and pressure (Ustaomer, Usta & Hiziroglu, 2008). In the past few years, MDF production has increased significantly and commands a large market share in the wood composite sector (İstek, Özlüsoylu, Ahmet & Onat, 2019). The homogenous edges of MDF enable precise machining and finishing methods to be applied. Thus, in many interior and exterior functions, such as in furniture, cabinets, moldings, window and door frames, and wall paneling, MDF is an incredible replacement for solid wood.

There are several parameters influencing how MDF is classified into three categories. The key physical properties comprise of density, moisture content (MC), and thickness swelling (TS) (Gul, Khan & Shakoor, 2017). Key mechanical properties include internal bonding strength (IB), modulus of elasticity (MOE), modulus of rupture (MOR), and screw holding force (face and side) (Gul, Khan & Shakoor, 2017). Thirdly, the key production parameters are hot-pressing temperature, applied pressure, and press time, mat moisture content (MMC), and assembly time (Gul, Khan & Shakoor, 201).

The raw materials used in this study for making MDF are *Sesbania aculeata* and *Tamarix aphylla*. *Sesbania aculeata* is a semi-annual legume herb, commonly used by farmers in South-East Asia for hundreds of years as green manure in its juvenile state, and as a fuel when matured. It only recently became a potential source of fibrous raw material for wood panel production. The plant grows

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exceptionally fast and can achieve yields of more than 20 bone-dry metric tons per hectare in its short life cycle. It is a good raw material for the manufacture of particle boards, and it can be used as biomass for the production of sugar (Mantanis, Athanassiadou, Barbu & Wijnendaele, 2018). Abd Rahman, Yatim, Zlan, Kasim & Yunus (2019), reported the importance of using fast growing species to support the wood composites industry. Meanwhile, *Tamarix aphylla* is a fast-growing, medium-sized evergreen tree, up to 18 m tall, with an upright tapering trunk, approximately 60-80 cm in diameter at breast height, and having many stout, purplish-brown, smooth branches. The wood is smooth, light-colored, fibrous and relatively hard, with a high shock resistance; it also polishes well and splits easily when first cut (Mantanİs & Birbilis, 2010)

The purposes of this study were to determine the physical and mechanical properties of 3.2 mm MDF from a commercial production line, and to evaluate the effects of production line speed, fiber moisture content, and production shift on the board properties.

2. Materials and Methods

Sesbania aculeata and *Tamarix aphylla* wood were used as the fibrous feedstock and mixed in 80% to 20% ratio. The MDF was designed to target the density range between 650 to 700 kg/m^3. The resin used was urea formaldehyde (UF) fixed at 8% content.

Generally, the wood is processed with a chipper machine into chips. The chips are separated to specific size ranges during screening. Then, confirmed chips are transported to a chips washer with a belt conveyor having an iron remover mounted over it. Washing improves the quality of the chips. The chips are cooked at a temperature within 160 – 180 ºC at a pressure of 6 - 8 bar for about 3 to 5 minutes, to soften them. Paraffin wax is added to the softened chips to make them resist moisture induced swelling. The softened chips are then transferred to a grinding chamber also known as defibrator. The chips are mechanically defibrated with water and heat. Pulp formed is conveyed through a blow line where UF resin is added to the pulp, followed by controlled moisture evaporation in the dryer. Resinated fiber is then uniformly distributed by air classification onto the matting conveyor belt to a thickness of 16 mm. The formed mat is pre-pressed to dispel the air out of the mat, and this also gives holding strength to the mat. The pre-pressed mat is then cured under specific pressure and temperature for a specific time. Pressed board is cooled before conveying to the longitudinal and transversal saws for cutting and trimming the board.

This work includes a study of the basic processes and current practices of MDF manufacturing. It identifies the effects of production line speed, fiber moisture content, and production shift on board properties for 3.2 mm thickness board. Finally, the results were compared to the European standards. ANOVA, DMRT, independent samples t-tests, and correlation analysis were conducted in analysis of the data using the IBM Statistical Package for the Social Sciences (SPSS) to determine significant differences induced in the properties. Nested design and factorial design were used in this experiment.

3. Results and Discussion

3.1 Data on MDF from *Tamarix aphylla* and *Sesbania aculeate*

The MDF was made from *Sesbania aculeate* (80 %) and *Tamarix aphylla* (20 %) at various production line speeds, fiber moisture contents, and shifts of mill operation, while adhesive use was held fixed at 8 %. Considering the differences in densities of the MDF board samples, specific MOR, MOE, IB and TS of each MDF case was determined with the results summarized in Table 1.

The MDF data show that for operations during morning, evening, and night shifts, the density ranged from 620 kg/m^3 to 690 kg/m^3. The averages by shift of bending strength and IB of MDF meet the requirements for general purpose boards for use in dry conditions. The averages of MOR and IB of tested MDF panels exceed the minimal values for general purpose MDF (20 MPa for MOR and 0.55 MPa for the IB) as defined in the standards EN310 and EN319, respectively. However, the average MOE in bending test of MDF panels exceeded the maximum values for general purpose MDF (2700 MPa) defined in the standard EN310. The average thickness swelling after 24 h immersion in water was above 12%, exceeding the minimal values for general purpose MDF (8 %) defined in the standard EN317. This may be due to a lower resin content in the middle of the board.

Regression equations to relate the board properties with the manipulated factors line speed, fiber moisture content, and production shift, are given in Table 3. Regression analysis of the data revealed that there is a good relationship between main factors and board properties with R^2 values exceeding 0.8.

3.2 Effects of production line speed

The effects of production line speed on mechanical properties are given in Figure 1. The mechanical properties showed higher values with decreased line speed. ANOVA comparison shows that the mechanical properties are significantly different at $p<0.05$. Significant difference in MDF production line speed was observed by production shift. Correlation analysis (Table 2) indicated that the properties MOR, MOE and internal bond decreased as line speed increased (r = 0.62**, 0.25, 0.37 and 0.13 and respectively). The production line speed at 5.50 m/min gave a significant rise (29.40 MPa) in bending strength compared to 6.00 m/min (25.35 MPa) and to 5.60 m/min (25.79 MPa). Both 5.60 m/min and 6.00 m/min show a relevant result, which makes both line speeds appropriate for optimizing production. As observed in Figure 2 on the production line speeds, MOE during production line speed at 5.60 m/min is slightly (2916 MPa) compared to line speed at 5.50 m/min (2732 MPa) or to 6.00 m/min (2705 MPa). The graph also shows that even at 5.60 m/min the MOE values for both 5.50 m/min and 6.00 m/min are exceeding the maximum standard values (EN310, 2700 MPa).

Production line speed plays a significant role for most of the processing. For the produced MDF those three alternative production line speeds affected MOR, and the

Table 1. Mechanical and physical properties of MDF made from *Sesbania aculeata* and *Tumarix aphylla.*

Line speed (m/min)	Fibre M.C (%)	Adhesive (%)	Shift operation	Density (Kg/m^3)	MOR (MPa)	MOE (MPa)	Density (Kg/m^3)	IB (MPa)	Thickness swell (24hrs) (%)
5.50	9.50	8.00	Morning	681	27.83	2275	670	0.66	12.54
			(1)	681	29.87	2832	656	0.66	12.53
				681	29.44	2891	669	0.63	12.55
				676	28.90	2843	662	0.65	12.53
				672	29.96	2716	654	0.64	12.55
				668	30.50	2836	666	0.67	12.54
Average				677	29.42	2732	663	0.65	12.54
6.00	8.70	8.00	Evening	690	27.11	2819	685	0.61	16.80
			(2)	683	26.16	2818	688	0.66	16.81
				677	25.98	2763	678	0.61	16.79
				678	22.77	2587	678	0.60	16.81
				686	23.58	2622	673	0.59	16.79
				688	26.48	2620	674	0.57	16.80
Average				684	25.35	2705	679	0.61	16.80
5.60	9.80	8.00	Night	649	25.16	2905	652	0.57	17.30
			(3)	649	25.54	2833	650	0.54	17.31
				655	25.84	2976	666	0.67	17.29
				664	26.01	2895	661	0.65	17.31
				653	25.52	2927	657	0.63	17.29
				659	26.65	2959	664	0.59	17.30
Average				655	25.79	2916	658	0.61	17.30
Range					20-30	2200-2700		0.55-0.75	<8 - 12%
Standard					EN310	EN310		EN319	EN317

Table 2. Correlation coefficients of the line speed, fiber moisture content and production shift on board properties

Variables	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
Speed	-0.62**	-0.25ns	-0.37ns	0.96**
Fibre M.C	0.30ns	0.45ns	0.16ns	-0.96**
Shift	-0.67**	0.45ns	-0.47ns	-0.04ns

Note: ns = no significant correlation *Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

Table 3. Regression analysis of effects of line speed, fiber moisture content and production shift on board properties

Model	R	R^2
Speed	0.993[a]	0.985
Fibre M.C	0.992[a]	0.983
Shift	0.997[a]	0.995

Note: [a]Predictors: (Constant), TS, SW, IB, MOE, MOR

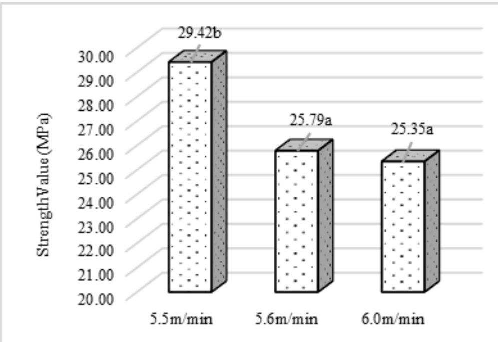

Figure 1. Effects of line speed on modulus of rupture

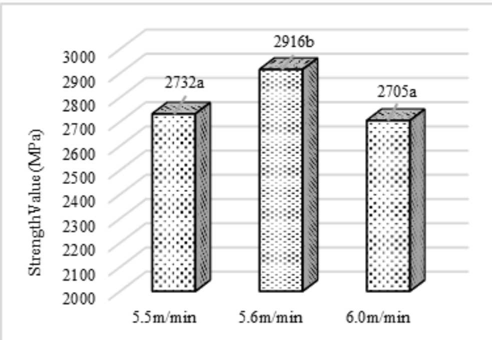

Figure 2. Effects of line speed on modulus of elasticity

results fall in the requirement range (20 MPa-30 MPa) of the standard EN310. However, the high MOR at 5.50 m/min can indicate potential to reduce power consumption from the long press time. Based on the results obtained regarding effects on MOE, the power consumption should be less. According to Gul, Khan & Shakoor, 2017, if the rate of steam consumption increases, the power consumption also increases. In this study, both line speeds of 5.50 m/min and 6.00 m/min can produce high values of MOE at a low steam consumption.

For IB, production line speed of 5.50 m/min gave the highest value (0.65 MPa) surpassing 5.60 m/min (0.61 MPa) and 6.00 m/min (0.61 MPa). Table 3 shows the R^2 value of 0.98 indicating direct impact of line speed, giving rise to differing compaction in the board (fiber bonding). The standard required value of IB is 0.60MPa, which clearly highlights the need to optimize production at line speeds of 5.60 m/min and 6.00 m/min (Figure 3). Sa'ad, Yunus, Ab Rahman & Rahman (2019), reported on board compaction

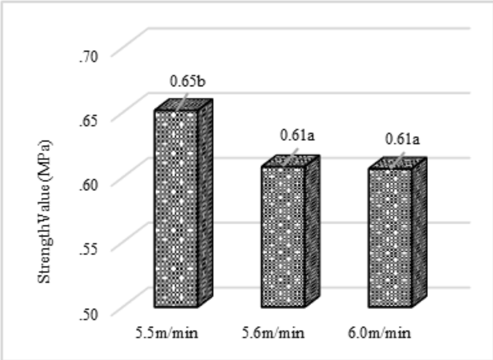

Figure 3. Effects of line speed on internal bond

contributing to bonding properties. The IB strength is a predominant and widely determined property of board (Park & Shin, 2014). Some factors that effect the IB strength during commercial production include the adhesive bond strength, fiber surface area, internal mat surface, fiber acidity, and hot-pressing phases. The tensile strength observed shows that the structure of MDF has good adhesion, which guarantees good dimensional stability of the panel and high mechanical characteristics. The physical and mechanical characteristics can help a manufacturer prevent costly mistakes and changes in production line speed. Based on the observations, 6.0 m/min offers a better output rate, decreased idle time and reduced production costs (Mahmood, Moniruzzaman, Yusup & Akil, 2016). Figure 4 shows the effects of line speed on thickness swelling in 24 h test. It shows the line speeds of 5.60 m/min and 6.00 m/min being not significantly different, but boards from both conditions were significantly different from 5.50 m/min production line speed.

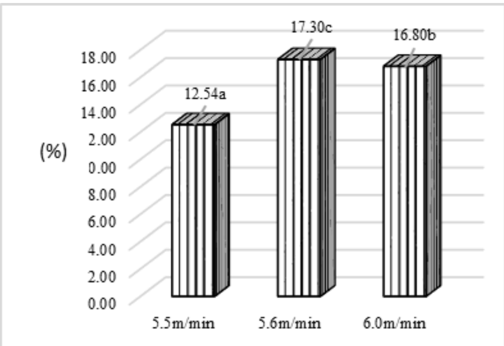

Figure 4. Effects of line speed on thickness swelling (24 h)

3.3. Effects of fiber moisture content

The effects of fiber MC of MDF are shown in Figures 5, 6, 7 and 8. The MC in the board influences its properties after the manufacturing. In Figure 5 the data show fiber MC at 9.50% giving MOR its highest value. The fiber MC shows a significant interaction in 9.50%. However, no significant interaction effect of fiber MC at 8.70% and 9.80% were seen. The MC also affects the MOE as shown in Figure 6. There is a significant difference in the fiber MC at 9.80% giving the highest (2916 MPa) superior to the 9.50% (2732 MPa) and 8.70% cases (2705 MPa).

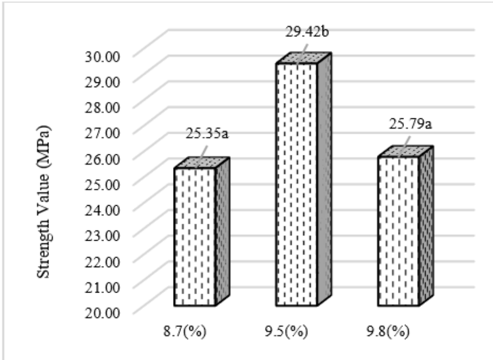

Figure 5. Effects of fiber moisture content on modulus of rupture

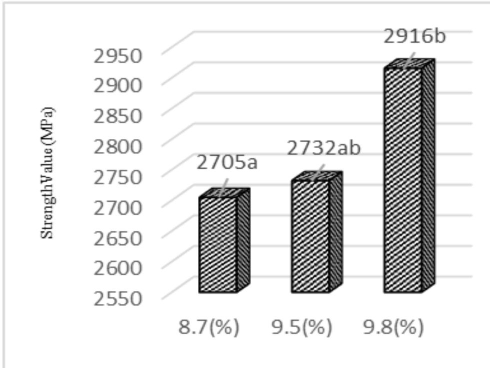

Figure 6. Effects of fiber moisture content on modulus of elasticity

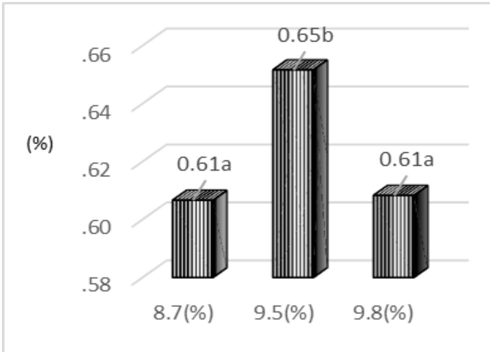

Figure 7. Effects of fiber moisture content on internal bond

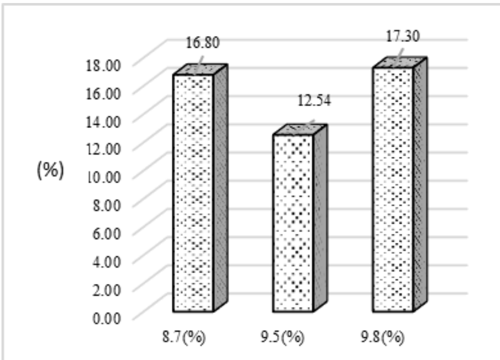

Figure 8. Effects of fiber moisture content on thickness swelling (24 h)

Figure 7 shows the effects of MC on IB for 8.70%, 9.50% and 9.80% cases with MC at 9.50% (0.65 MPa) giving the highest value. This result applies to the morning shift and has a close relationship to the MOR value.

Figure 8 is the effect of the MC on the TS in 24 h results. From the data, the MC at 9.80% (17.30%) had the strongest influence giving the largest TS over the other cases with MC at 8.70% (16.80%) and at 9.50% (12.54%). The correlation analysis (Table 2) revealed that fiber MC had a negative correlation (r = -0.96**). This indicates that higher fiber moisture content contributed to higher water intake by the MDF board.

The wood material tends to absorb or release moisture until it reaches an equilibrium with its surrounding environment. The MC of MDF can have an enormous impact on the quality of MDF. It can also impact the process during production. An excessive fiber MC can cause problems, including preventing adhesives from making a secure bond; and as excess moisture leaves the fiber, it can cause shrinkage. When MDF is exposed to water, the wood fibers swell and residual stress that was created during the MDF pressing is released, increasing MDF thickness. This thickness swelling also reduces the strength characteristics of MDF (Ayrilmis, Jarusombuti, Fueangvivat & Bauchongkol, 2010). Regarding structural variations, tensile properties were identical for all composites, leading to the assumption that the initial MC of fibers was not a large factor regulating the mechanical properties of MDF from *Sesbania aculeate* and *Tamarix aphylla*. Mechanical performance against fiber MC might be explained either by competitive phenomena or by the fact that structural changes were not sufficient to affect the mechanical properties of the MDF. The observed values show that fiber MC (8.7 %) meets the requirements on physical (TS) and mechanical characteristics (MOR, MOE and IB).

3.3. Effects of production operation (Morning, evening & night shifts)

The production shift influences the MOR, MOE, IB and TS as shown in Figures 9, 10, 11 and 12, categorized by morning, evening and night shifts. The data were recorded during the winter season (December to January). The average temperatures were: in the morning 12°C, evening 24°C, and night 14°C. In Figure 9 the morning shift gave slightly larger MOR of 29.42 MPa than evening (25.35 MPa) or night shift (25.79 MPa). Table 2 shows that production shift had a negative correlation (r = -0.67**) with the MOR. This is due to the cooler temperatures during the morning shift. Figure 10 shows the MOE influences by production shift. The data show the highest values during night shift (2916 MPa) followed by the morning shift (2732 MPa) and evening shift (2705 MPa).

In IB strength (Figure 11), evening and night shifts had no significant difference, but board from morning shift had the highest value (0.65 MPa). Again, the cooler temperature during the morning shift contributed to this better performance. Figure 12 shows the effects of production shift on thickness swelling in 24 h test, with morning shift giving the lowest TS (12.54%) and evening (16.80%) and night (17.30%) shifts giving larger TS. This shows that the morning shift produced the best adhesive bonding during the production.

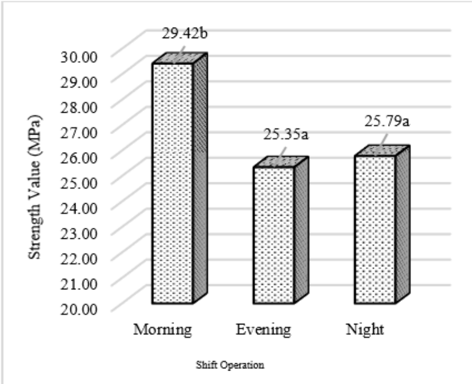

Figure 9. Effects of production operation on modulus of rupture

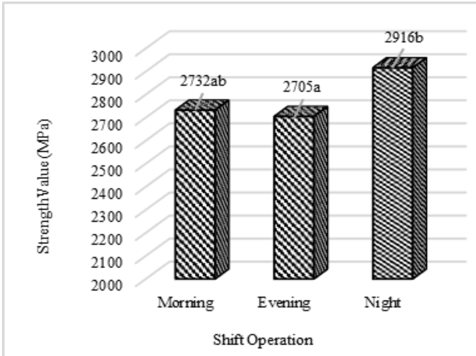

Figure 10. Effects of production operation on modulus of elasticity

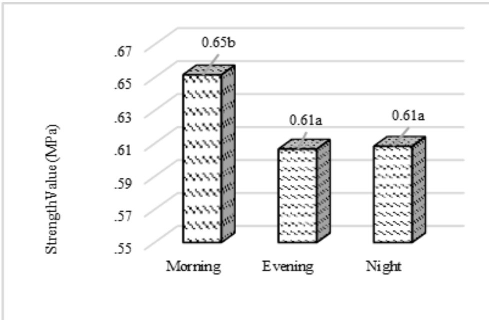

Figure 11. Effects of production operation on internal bond

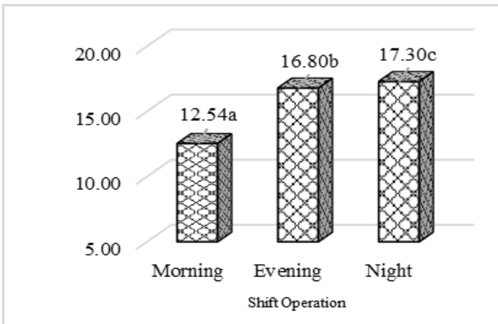

Figure 12. Effects of production operation on thickness swelling (24 h)

Production shift may influence properties of the manufactured MDF panel. The effects of production shift on MOR, MOE, IB and TS indicate that evening is favorable compared to morning and night shifts. This is indicated by the correlation coefficient of production line speed and fiber moisture content. This is despite the highest TS among the shifts. The board dryness (MC) allows more water absorption thus leading to higher swelling.

4. Conclusions

Utilization of *Sesbania aculeata* and *Tamarix aphylla* as alternative fiber sources in MDF production was assessed with mechanical and physical characterizations, with reference to adopted standards. The MDF production line speeds, fiber moisture contents, and production shifts were compared. It was observed that the mechanical properties MOR, MOE and IB were ideal for the production of MDF during evening shift, with a line speed of 6.00 m/min and 8.70 % fiber MC.

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