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The Machining Characteristics of Oil Palm Empty-Fruit Bunches Particleboard and its Suitability for Furniture

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Abstract: A series of machining experiments were carried out using a CNC router, with single fluted router-bits, to evaluate the machining and tool wearing properties of the particleboard made from oil palm empty-fruit bunches. The result found that the resultant machined surface of the oil palm particleboard was poor with an increased incidence of defects such as tear out and chip out on the edges of the panels compared to wood particleboard. Further, the material showed increased abrasiveness on the cutting tools due to its high silica content. Despite the shortcomings, the lower cost and environmental friendly reputation of the panels will further encourage its use in the furniture industry, especially in concealed applications.

Key words: Oil palm, particleboard, machining, furniture, process economics

INTRODUCTION

Over the past 30 years, the worldwide area planted to oil palm (*Elaeis guineensis* Jack.) has increased by more than 150% (Khalil *et al*., 2006). Most of this increase has taken place in Southeast Asia, with spectacular production increases in Malaysia and Indonesia. There are several reasons for this rapid expansion. Crude palm oil and kernel oil prices have been strong, due to the rapid increase in consumption of dietary oils and fats in the developing economies of China and India. This has encouraged investors to develop plantations on the large areas of suitable land found in Malaysia and Indonesia.

Malaysia has about 3.5 million ha of oil palm producing annually over 10 million tonnes of crude palm oil, making it the world's leading producer of the oil (Khalil *et al*., 2006). However, Crude Palm Oil (CPO) and its economic co-products palm kernel oil and palm kernel cake, constitute only 10% of the crop, leaving the rest of the biomass to waste. The biomass includes the oil palm trunks and fronds, p alm-kernel, Empty-Fruit Bunches (EFB), pressed fruit fibre and palm oil mill effluent. At present, these products are not only underutilized but frequently the causes of pollution as well (Khalil *et al*., 2006).

The large volumes of these products and their environmental friendliness makes imperious for their use in economic products. The Empty Fruit-Bunches (EFB) produces approximately 4 million tons of fibers per annum (Khalil *et al*., 2006). EFB is the residual bunch after removal of the fruits; it constitutes 20 to 22% of the weight of the fresh fruit bunches. On average, fresh EFB from the mill contains 30.5% lignocellulose, 2.5% oil and 67% water. The main constituents of the lignocellulose are cellulose (45%), hemicellulose (32.8%) and lignin (20.5%). Of the hemicellulose, pentosan is 27.3%.

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At present, EFB is mainly used as mulch, but the economics are marginal due to the high transport cost. It is seldom burnt as fuel, as the shell and fruit fibre are sufficient for the oil palm mill (Ellis and Paszner, 1994).

Recently, EFB has been investigated as a raw material for building materials, solid fuel pellets, chemical products, particleboard, fibreboard, blackboard and pulp and paper (Gabriele, 1995). Although particleboard can be produced from any lignocellulosic material (Lathrop and Naffziger, 1994), very little is known about using EFB for it.

Lately, particleboard production in Malaysia has increased exponentially. The country now has 7 particleboard mills, mostly using Rubberwood (*Hevea brasiliensis* [Willd. ex A. Juss.) Müll. Arg.]) as their major raw material. Projections show that in the near future the supply of Rubberwood will not meet the demand for making particleboard due to its competition and demand from the Medium Density Fibreboard (MDF) manufacturing industry (Hong and Sim, 1994). The first commercial plant for the production of oil palm EFB particleboard has been in operation in Malaysia recently, with a production capacity of 20,000 m^3 per annum. Despite the industrial success, the oil palm particleboard has limited market acceptance in the furniture industry, due to the lack of information on its machining characteristics and its associated costs (Ratnasingam and Scholz, 2006). Although the oil palm particleboard has a lower production cost and comparable mechanical properties compared to the conventional wood-based particleboard, its machining characteristics will influence its acceptance in the market as a material for furniture applications. Therefore, a study was undertaken to evaluate the machining properties and the related costs of particleboard made from EFB, in order to provide information on its potential application for furniture.

MATERIALS AND METHODS

Three-layered oil palm particleboards of the dimensions 1500×2000×12 mm were obtained from the only manufacturer in Malaysia. The properties of the boards are as shown in Table 1. The boards were conditioned in a controlled environment at a temperature of 20°C and 70% relative humidity for a week prior to experimentation. The study was conducted at the manufacturer's test laboratory in November, 2007 and the experimental scope is as shown in Fig. 1.

A series of boring, sawing and edge profiling tests were conducted on 50 experimental boards, in accordance with the American Society of Testing and Materials (ASTM) standard for evaluating the machining properties of wood materials (Anonymous, 1999). The machining quality was evaluated on the basis of percentage defect-free surface produced after each machining tests.

The tool wearing study was carried out using an ANDERSON-810 Computer Numerical Control (CNC) router. Two types of tungsten-carbide cutting tools were used in the experiments, i.e. solid cutter and insert-knife. The router bits used were single fluted, both solid and those using the insert knives, of 12 mm in diameter and 15° rake angle and rotating at 18,000 revolutions min^{-1}, was used to machine the boards over a total machining length of 10,000 m. The feed speed and depth of cut were fixed at 4.5 m min^{-1} and 1.5 mm, respectively. The cutting tool travelled along the length of the experimental board and retracted automatically to the starting point before resuming the next cutting operation. Due to the high silica content in the oil palm fiber (Sreekala *et al*., 1997), the highly wear

Table 1: Characteristics of oil palm particleboard

Average board density (kg m^{-3})	700
Average moisture content (%)	10±2.0
Nominal thickness (mm)	12.0
Urea-based adhesive content (%)	6.0
Pressing time (min)	6.0
Pressing temperature (°C)	170.0
Pressing pressure (N mm^{-2})	6.5

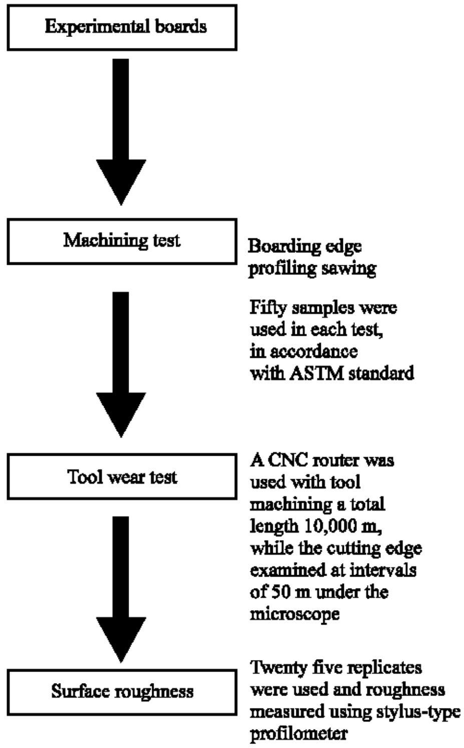

Fig. 1: Experimental Scope

Table 2: Composition of tungsten carbide tools

Tool	WC content (% of weight)	Co content (% of weight)	Cr content (% of weight)	Average carbide particle size (μm)
Grade A	88.5	10	1.5	1.6
Grade B	87.5	10	2.5	1.4
Grade C	86.5	10	3.5	1.0

resistant tungsten carbide cutting tools were selected for this study (Bayoumi and Bailey, 1985). In this study however, three different compositions of tungsten carbide was used, in order to establish the optimal grade of tungsten carbide for cutting oil palm particleboard (Table 2). The extent of cutting tool wear during the machining operation was measured using the cutting edge-recession technique at intervals of 500 m along the total machining length, as described in (Ratnasingam and Perkins, 1998). Since, cutting edge-recession has a direct link to tool life, it allow the cost of tooling to be determined when machining the experimental boards. Microscopic examinations of the cutting edges were done at the end of the experimentation to characterize the mode of failure in the cutting tools. The power consumption during the machining operation was also measured on the basis of the changes in the torque of the drive-motor of the CNC router, as described in Ratnasingam and Scholz (2006).

A two-head TIMESAVER-220 wide-belt sander with steel rollers, with silicone-carbide abrasives, of the sanding grit sequences 120-150 were used to evaluate the resultant surface smoothness on the oil palm particleboard. A total of 25 sample boards of the dimensions 500 ×1000 ×12 mm were used in this study. The sanding pressure was fixed at 6 kg cm^{-2}. The surface smoothness of the sanded palm oil particleboards were evaluated using a MITUTOYO stylus-type profilometer as described by Hiziroglu (1996), which measured the average surface roughness (R_a) in microns over ten sampling points per board.

For comparison, a series of similar experiments of equal number of replicates were carried out on wood particleboards obtained from a local supplier. The wood material used in these particleboards was Rubberwood, which was the most commonly produced particleboard in the country.

RESULTS

Machining Characteristics

The prevailing density profile in the oil palm particleboard explains the poor machining characteristics of the material (Ratnasingam and Scholz, 2006). The oil palm particleboard performed poorly in the boring, edge-profiling and sawing tests, with an average defect-free surface of less than 40% (Table 3). The most common defects encountered when machining oil palm particleboard were tear-out and chip-out, especially on the edges of the boards, which is most likely due to the differential density within the fibers as well as within the core and the face of the particleboard (Klamecki, 1980). Further, the higher toughness of the oil palm fibers also makes its cutting difficult (Sreekala *et al*., 1997). It is apparent that the oil palm particleboard has poor machining characteristics compared to wood particleboard and its acceptance for furniture application will depend on improvements in its machining characteristics, possibly through chemical modification of the fibers (Ratnasingam and Scholz, 2006). It has been suggested that bulking the fibres using phenolic resins may improve the stability of the fibres in the boards, hence improving its machining quality.

Tool Wear Characteristics

The tool wear pattern as reflected by the change in tool-edge recession over the cutting length, when machining the oil palm particleboard is shown in Table 4. It seems apparent that the tool wear pattern occurs in three phases, which is similar to the machining of conventional wood particleboard (Klamecki, 1979; Ratnasingam and Tanaka, 2002). However, the accelerated tool wear rate when machining the oil palm particleboard was significant, as the tool was completely worn out after 2800 m of cut. The high silica content (6%) in the oil palm fibers and the adhesive binders used in the manufacture of the particleboard, imparts a high degree of abrasiveness to the boards, which accelerates the tool wear (Sreekala *et al*., 1997, 2001). Microscopic examination of the cutting tool edge reveals that the predominant tool wear mechanism is micro-indentations and fractures on the tool face, arising from the contact with silica cells in the fibers (Law *et al*., 2007), followed by mechanical abrasion. Such wear mechanisms are typical in materials with high impurities content, such as silica, that resulted in the removal of the binder followed by the loss of the carbide grains from the cutting tool (Bayoumi and Bailey, 1985). Further, the oil palm particleboard was more abrasive by a factor of 2, compared to the conventional wood particleboard (Table 4). The comparative wear rates of tools of the three

Table 3: Comparative machining tests

Machining process	Defect free surface with oil palm particleboard (%)	Defect free surface with wood particleboard (%)
Boring	56	69
Sawing	49	65
Edge profiling	30	58

Table 4: Extent of wear of the various grades of cutting tool

Tool	Edge recession (μm) at 500 m	Edge recession (μm) at 1500 m	Edge recession (μm) at 2000 m	Cut distance (m) at tool failure	Average power consumption (W) per m length of cut
Grade A	120 (67)	175 (90)	219 (115)	1650 (3440)	80 (46)
Grade B	93 (45)	139 (72)	181 (96)	2380 (4810)	62 (35)
Grade C	55 (29)	97 (49)	138 (67)	2800 (5080)	51 (27)

*Values in parentheses are the values for wood particleboard different compositions are also shown in Table 4. The best performance, in terms of tool edge recession and distance of cut before failure, was obtained from the grade C tool, with the highest chromium content in the matrix and smallest carbide particles. Complete cutting tool failure for the three grades of cutting tools occurred after cutting distances of 1650, 2380 and 2800 m, respectively. This is in line with the study by Bayoumi and Bailey (1985), who found that higher chromium content in the tool matrix and smaller carbide particles improved the wear resistance of tungsten carbide tools. Therefore, optimizing the machining process of oil palm particleboard will require the use of highly wear resistant tools.

Since power consumption during the machining process is correlated to the cutting tool wear, the power consumption was the least with the high chromium content tungsten carbide tools (Table 4). The improved wear resistance of the grade C cutting tool ensured lower power consumption during the machining operation, which in turn improved the process economics. Further, disposable knife inserts provide a longer tool life compared to solid cutters, a feature that must taken into consideration when machining oil palm particleboard (Ratnasingam and Scholz, 2006).

Surface Roughness

The average surface roughness of the abrasive sanded oil palm particleboard was 138 μm, compared to 108 μm for conventional wood particleboard, using the abrasive sanding grit sequence of 120-150. The difference in average surface smoothness of the two types of particleboard is most likely due to the different fiber morphology (Ratnasingam and Scholz, 2006). According to Law *et al*. (2007), the oil palm fibers have thicker cell walls and higher coarseness and rigidity compared to Rubberwood (*Hevea brasiliensis*). Further, the significantly different densities between the fiber bundles and parenchyma cells in the oil palm fibers, creates an inherent density gradient within the material, which could explain the variable surface topography during abrasive sanding. Nevertheless, it must emphasized that in terms of surface smoothness, the oil palm particleboard is not significantly inferior to the wood particleboard, indicating that the material should perform well in furniture applications.

Industrial Implications

On the basis of the machining experiments conducted, it is apparent that the machining properties of the oil palm particleboard are poorer compared to that of the wood particleboard, especially when machining the edges of the boards. In terms of the tooling cost, Table 5 provides comparative tooling cost for machining oil palm particleboard and the wood particleboard. Although the tooling cost is estimated to be twice for machining oil palm particleboard, the use of disposable knife inserts provides an economical option for furniture manufacturers to reduce the tooling cost significantly (Table 5). Nevertheless, it must be recognized that the existing conventional cutting tools are not suitable for the machining of oil palm particleboard and hence, development of special cutting tools is warranted. Against this background, the oil palm particleboard may find widespread acceptance in furniture applications, where lower product costs may be warranted at the expense of lower machined surface quality. The use of oil palm particleboard appears to be well suited in concealed applications for furniture, such as in upholstered seats, cabinet door inserts etc.

Table 5: Comparative tooling cost for machining oil palm particle board and wood particle board

Parameters	Oil palm particleboard	Wood particleboard
Cost of tool (US$)	20 (10)	20
Cost per grind (US$)	1.50 (0)	1.50
Number of grind	5 (0)	5
Edge life per grind	2,800 (2,800)	5,080
Overall cost	27.5 (10)	27.5
Life time per tool (m)	14,000 (11,200)	25,400
Cost per meter cut during life time of tool (US$)	0.002 (0.001)	0.001

*The values in parentheses are for the insert-knives

CONCLUSIONS

Although this study shows that particleboard from oil palm EFB fibre has machining properties below the commercial standard of that of the wood particleboard, its competitive costs will render it suitable for furniture applications, where economics is more important than surface quality. The fact that oil palm particleboard is made from biomass of recycled waste, clearly renders the material a more environmental friendly stature compared to conventional wood particleboard and will therefore be more acceptable in the future environmental conscious marketplace.

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