A Comparison of the Abrasive Sanding Dust Emission Characteristics of Oil Palm Wood and Rubberwood

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With the increasing interest in using oil palm wood (OPW) in the manufacture of value-added wood products in the South East Asian region, the subject of dust emission in relation to the variable density of OPW is a matter of concern. Therefore, this study evaluated the dust emission characteristics of untreated and phenol-formaldehyde-treated OPW during the abrasive sanding process. Rubberwood was the solid wood material used in this study for comparison purposes. The abrasive sanding process was carried out using an orbital sander with aluminium oxide abrasive paper with a grit size of 150. The sample boards were weighed before and after sanding to determine the amount of stock removed. The dust concentration and dust particles diameter was influenced by the material type, material density variation, and material hardness. The study revealed that both untreated and treated OPW produced higher dust concentration and higher proportions of fine respirable dust particles compared with rubberwood during the abrasive sanding processes, and therefore, it is important for a more stringent permissible exposure level (PEL) standard for dust emission to be established for OPW processing. In this context, the existing PEL of 5 mg/m^3 of dust is inappropriate and needs a revision if OPW is to be successfully used in the value-added wood products industry.

Keywords: Abrasive sanding; Oil palm wood; Dust; Density; Hardness

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INTRODUCTION

With nearly 13.5 million hectares of land under cultivation in South East Asia in 2017, oil palm (*Elaeis guineensis*) has emerged as the fastest expanding plantation tree crop in the region. The oil palm tree is native to West Africa. Planted primarily for the production of palm oil—a product that is used around the world—it also produces a substantial amount of biomass that could become an important source of raw material for the wood products industry. Oil palm trees are usually felled for replanting after 25 to 30 years, when the palm oil yield becomes too low to be economically viable. The wood from the oil palm tree trunk (OPW) is a by-product that could become a promising alternative raw material to supplement the diminishing solid wood supply for furniture and other value-added products manufactured in the South East Asian region.

The most common wood resource presently used in the manufacture of furniture and other value-added wood products in Malaysia and its neighbouring countries is rubberwood (*Hevea brasiliensis*). The rubber tree, which is native to South America, was introduced to the region by the colonial masters in early last century, and it has quickly emerged as one of the most important plantation tree crops in the region. Cultivated primarily for latex or natural rubber production, the rubber trees are usually felled and replanted after a period of 25 to 30 years, when the latex production has decreased significantly (Ratnasingam *et al.* 2011). The wood resource derived from the rubber tree has emerged as an environmental-friendly and sustainable wood resource with excellent working properties, rendering it a high demand from manufactures of furniture and other value-added wood products. However, with the slump in the latex prices worldwide and the stiff competition arising from synthetic rubber, the area under rubber cultivation has gradually shrunk over the years, as growers shift towards the cultivation of oil palm, which provides a much higher economic return. As the rubber growers are predominantly smallholders (*i.e.* those with cultivation areas of less than 16 hectares), the economic viability of rubber cultivation is of paramount importance to them, as their livelihood is dependent on the global latex prices. In fact, growing rubber do not give the return previously enjoyed, and many of the growers need substantial government assistance in order to maintain an economic livelihood (RRIM 2018).

Against this background, there is increasing pressure on the sustainable supply of rubberwood in the country, and many manufacturers of furniture and other value-added wood products have to cope with the higher price of the rubberwood stock, which in turn adversely affects their bottom-line (Ratnasingam *et al.* 2011). In this context, the OPW appears to be a promising raw material for the booming wood products industry in the country, which is constantly seeking alternative raw materials supply. Being environmentally friendly and low-cost, OPW has been explored for many different applications and is the most suitable for non-structural applications, in either solid form or laminated composites (Frühwald and Akrami 2014). Although the physical and mechanical properties of OPW have been extensively studied, the widespread application of the material is constrained by three inherent weaknesses: (1) the low density, especially in the middle and core of the trunk; (2) its highly hygroscopic nature, which makes it rather unstable; and (3) its poor machining characteristics due to its variable density and high silica content (Killman and Lim 1985; Sreekala *et al*. 1997; Lim and Gan 2005; Ratnasingam *et al.* 2008; Dungani *et al.* 2013). Impregnating OPW with synthetic resins, especially phenol-formaldehyde resin, can increase its density, which in turn improves the strength and stability of OPW. Much of the results of such previous studies have shown that through such impregnation practices, the higher density and stability gained by the OPW allows its use to be expended to applications that previously were excluded. While the economic viability of such practices have not been demonstrated yet, this promising evidence suggests that treated OPW has the potential to become an alternative substitute raw material for value-added wood products manufacturing. Nevertheless, in order to further boost the economic viability of impregnation treatment of OPW and to realize its potential use in the manufacture of value-added products, information on the effect of impregnation treatment on the machinability and dust emission of OPW is limited (Dungani *et al.* 2013).

The dust emission characteristics during machining processes is an important raw material criterion that determines its successful use in the manufacturing of products. Dust emission has a strong influence on the workers' safety and health, and it indirectly affects the manufacturing productivity (Harper and Muller 2002; Saejiw *et al.* 2009; Ratnasingam *et al.* 2016). Machining and abrasive sanding are important sources of dust emission in the manufacturing processes, but the latter has a more pronounced dust emission effect than the former. Abrasive sanding is an orthogonal cutting process with a negative rake angle; wood removal is achieved by crushing and scraping actions, which inevitably leads to higher amounts of dust emission (Ratnasingam *et al.* 2004). Furthermore, the resultant dust emission level is influenced by the density and hardness of the workpiece, abrasive sanding grit, type of abrasive mineral, and machining parameters (Saejiw *et al.* 2009; Ratnasingam *et al.* 2011).

In this context, the dust emission from OPW abrasive sanding processes is of particular interest because of its variable density, ranging from 500 kg/m^3 in the periphery of the trunk to 200 kg/m^3 in the core of the trunk. The objective of this study was to assess the characteristics of dust generated from OPW during the abrasive sanding processes in comparison to rubberwood, which was used as the control. The outcome of this study will have ramifications on the successful use of OPW as well as its acceptance as an alternative material for the value-added wood products manufacturing sector.

EXPERIMENTAL

Experimental Materials

Oil palm wood (both treated and untreated) and rubberwood, which is the most common wood species used in the Malaysian wooden furniture manufacturing industry, were selected for this study (Table 1). The rubberwood (*Hevea brasiliensis*) was obtained from a local sawmill, while the OPW was obtained from the local distributor of the material. The OPW from the middle and core of the oil palm trunk were pressure-impregnated with phenol-formaldehyde resin, to achieve a resin loading of 40%, to reduce its disparity in density in comparison to the OPW from the periphery of the oil palm trunk. The treated samples were obtained from a commercial supplier, who used phenol-formaldehyde resin supplied by Chemibond. The PF resin had a viscosity of 80 cps, with a pH of 13, while the specific gravity was 1.20. The impregnation was carried our using a pressure vessel which applied a pressure of 5 bar (0.5 N/mm^2), followed by a curing period for 2 hours at a temperature of 130 °C. All experimental materials were in the form of planks measuring 25 mm × 50 mm × 50 mm. The samples were conditioned in a climatic chamber maintained at 20 °C and at 65% relative humidity until a final moisture content of 12 ± 2% was achieved before experimentation. The experimental materials were cut into two pieces of equal lengths, where one was used for density and hardness determination, and the other was used for abrasive sanding experimentation. A total of 10 planks of each species were used in this study.

Table 1. Experimental Materials Used in the Study

Material	Average Density(g/cm^3)	Average Hardness (N)
OPW (Periphery)	0.50 (0.020)	3019 (119)
OPW (Middle)	0.39 (0.016)	2680 (91)
OPW (Core)	0.25 (0.013)	2010 (88)
OPW (Middle) Treated	0.49 (0.017)	2940 (103)
OPW (Core) Treated	0.46 (0.017)	2915 (101)
Rubberwood (*Hevea brasiliensis*)	0.54 (0.021)	3440 (131)

Note: Figures in caption refer to standard deviation

Evaluation of Material Properties

The density and hardness of the experimental materials were evaluated prior to the experimentation. The density of the experimental materials was evaluated using the gravimetrical approach. The hardness was evaluated by the Brinell technique as described in the standard EN 1534 (2000). In this method, the force applied (N) by an 8 mm Φ steel ball to result in a 2 mm depression on the surface was evaluated (Desch and Dinwoodie 1996). The density and hardness values of the experimental materials obtained in this study (Table 1) were within the 5% difference of the average published values of the respective wood specie and OPW (FRIM 2014).

Evaluation of Dust Emission

A 3 M pneumatically-operated orbital sander with an orbit diameter of 80 mm and rotating at 10,000 revolutions per min was used in the abrasive sanding experimentations. Figure 1 shows the sanding experiment configuration, which was adopted from the study by Ratnasingam *et al.* (2009, 2011). The paper-backed aluminum oxide abrasive of 150 grit size, was attached to the orbital sander using the Velcro hook and loop system. The abrasive 150 grit size was used, as it is the most common abrasive grit size used in the industry. The abrasive paper was changed every 2 hours, as per the abrasive paper supplier's recommendation.

The orbital sander was fixed in position by a specially made bracket, while the experimental plank was attached on to a reciprocating platform that moved at a speed of 15 mm sec^{-1}. A force equivalent to 5 kg (50 N) was applied on to the sander, to ensure consistent sanding operation. This experimental configuration represented the typical sanding operation in the wood products manufacturing industry, as reported by Ratnasingam *et al.* (2009).

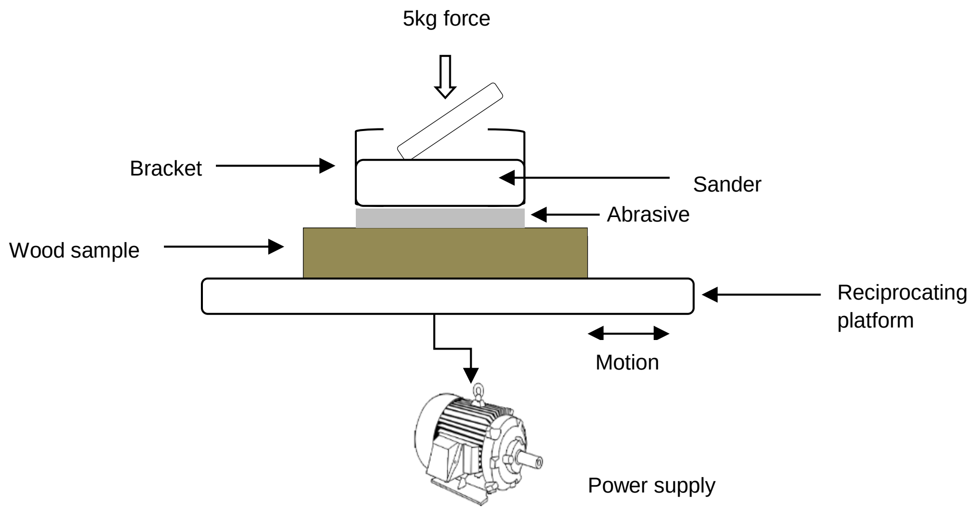

Fig. 1. Configuration of the abrasive sanding experimentation

The sanding experiments were carried out in an experimental dust tunnel with a moving air stream, and the air velocity was maintained at 25 cm sec^{-1}. The quantity of stock removed over a period of 60 min from the experimental materials was determined by weighing the sample boards before and after the abrasive sanding process.

Three gravimetric isokinetic air samplers were placed two meters apart, along the length of the air tunnel, to determine the average dust concentration during the abrasive sanding process. The size distribution of the dust particles was measured using an aerodynamic particle sizer (APS 3300, TSI Incorporated, Shoreview, MN, USA), which had a series of filters ranging from 28 μm to 0.5 μm. This also enabled the proportion of air-borne dust (particles > 10 μm in size) and respirable dust (particles < 10 μm in size) emitted during the abrasive sanding process to be determined. Inevitably, evaluating the proportion of air-borne dust to respirable dust particles can enable the necessary risk-avoidance measures that should be implemented to protect the workers safety and health when working with these materials. The experimental techniques, dust particle evaluation method, and statistical analysis used in this study were adopted from previous studies by Ratnasingam *et al.* (2009, 2011).

To establish the relative power requirement for dust exhaustion during the abrasive sanding process of the various experimental materials, the sanding experiments were repeated in a concealed experimental chamber of 1.0 m × 1.0 m × 1.0 m that was fitted with a WESTAIR portable dust exhaust system with variable exhaust air velocity. Based on the dust particles size distribution determined for each of the experimental materials, the exhaust air velocity was varied between 20 m/s to 30 m/s, to achieve the targeted permissible dust emission level of 5mg/m^3 as stipulated in the Factories & Machinery Act 1967 (DOSH 1978; Ratnasingam *et al.* 2011).

RESULTS AND DISCUSSION

Determination of Dust Concentration

According to Ratnasingam *et al.* (2011), the level of dust emission and the characteristics of the dust particles produced during the abrasive sanding process are closely related to the stock removal rate, sanding parameters, and material properties, especially its density and hardness. In this study, however, the focus was on the dust concentration during the abrasive sanding of the various experimental materials. As shown in Fig. 2, there was a direct relationship between the material density and its hardness.

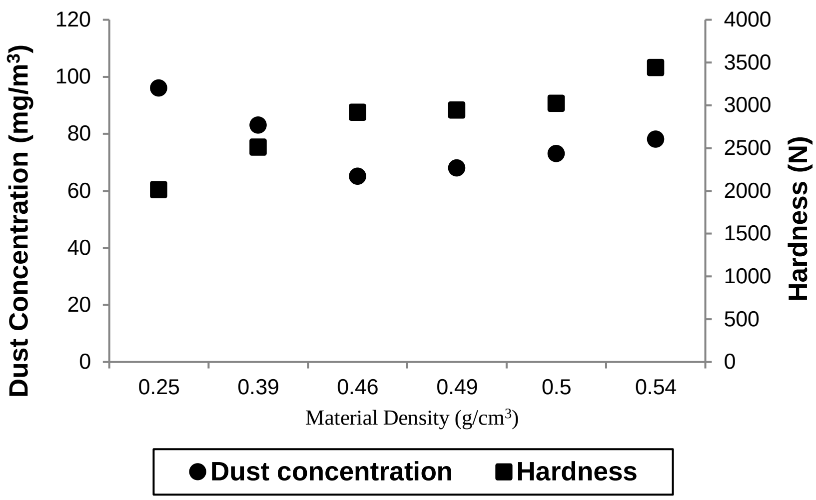

Fig. 2. Effect of hardness wood density on dust concentration

With a strong correlation coefficient of 0.901 between the experimental material density and hardness, it may be postulated that a similar correlation of other experimental parameters with the material density and hardness can be expected as well, as suggested previously by Desch and Dinwoodie (1996). Consequently, any change in wood density or hardness will result in a comparable change in the rate of stock removal and dust concentration during the abrasive sanding process. In the abrasive sanding process, the abrasive minerals penetrate into the stock, which leads to the removal of a layer of the stock equivalent to the depth of the mineral particle penetration. It must be recognized that in the abrasive sanding process, the crushing of cells and tissues is more pronounced in lower density compared to higher density materials, which explains the higher dust concentration observed (Ratnasingam *et al.* 2004).

In contrast, the unique anatomy of the OPW, in which the tough vascular bundles are embedded in the soft parenchyma tissues, show markedly variable densities. During the abrasive sanding process of OPW, the stock removal will obviously lead to the crushing of the softer parenchyma tissues compared with the harder and tougher vascular tissues (Frühwald and Akrami 2014). However, the number of vascular bundles per unit area also decreases significantly from the periphery into the core of the trunk (Frühwald and Akrami 2014). This finding explains the higher dust emission level observed when sanding the OPW from the middle and core portions of the oil palm trunk. However, the treated OPW with its higher density and hardness produces a noticeably lower concentration of dust than the untreated OPW. It is therefore apparent that treating OPW with synthetic resin minimizes the dust emission characteristics of OPW.

Effect of Density on Dust Particle Size Distribution

The geometric mean particle size and the particle shape of the dust produced during abrasive sanding is strongly influenced by the density and hardness of the material, rather than the sanding parameters used (Ratnasingam *et al.* 2004; Ratnasingam and Scholz 2015). Generally, softer and lower density materials produce coarser dust particles and *vice versa*. As reported by Ratnasingam and Scholz (2015), the abrasive grits penetrate deeper into the softer materials to remove a larger amount of wood material, resulting in coarser dust particles. Hence, the denser materials produce a higher amount of finer dust particles (< 10 µm), although at a lower rate compared to materials of lower density (Fig. 3). This is in line with the previous report by Ratnasingam *et al.* (2004), who found that the total amount of airborne dust produced is a function of the total amount of stock removed during abrasive sanding process, which in turn is affected by the material density and its hardness.

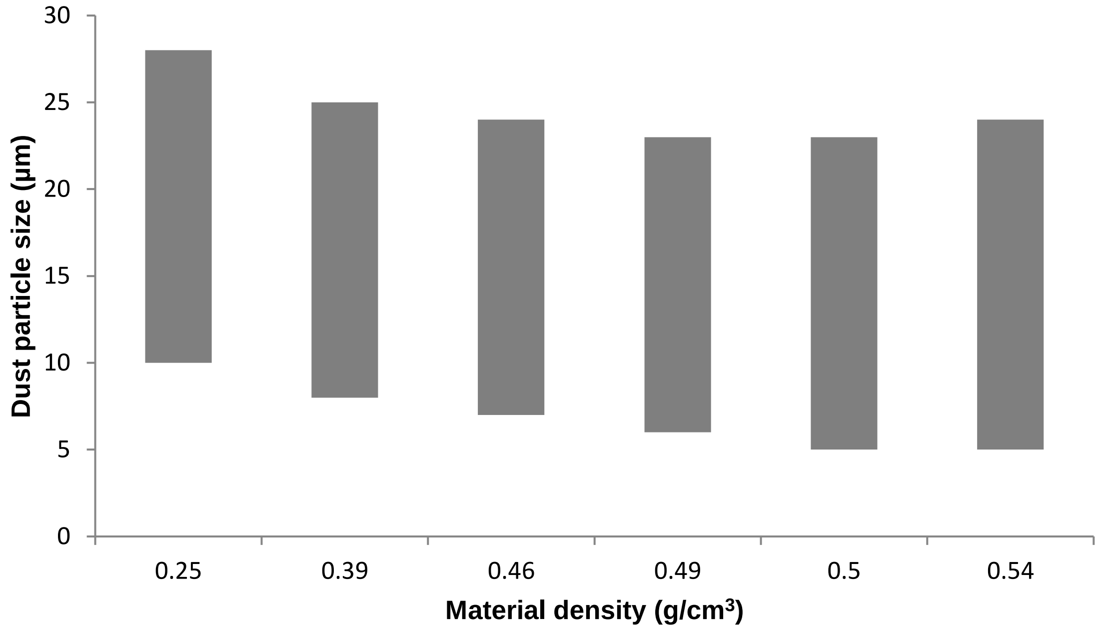

Fig. 3. Effect of wood density on range of dust particle size produced during abrasive sanding

This result confirms that the proportion of respirable dust particles (< 10 µm) in the total dust concentration produced is less related to the stock removal rate compared to the characteristics of the material (Table 2). As shown in this study, density and hardness of the material play an important role in determining the dust emission characteristics of the materials during the abrasive sanding process. Generally, spongy and weaker cells, such as the parenchyma cells in the OPW tend to produce more fine dust particles, as the cell wall is easily crushed during the abrasive sanding process (Frühwald and Akrami 2014). The OPW has a unique anatomy, as the number and characteristics of the vascular bundles vary in the OPW according to its position in the oil palm trunk. The study by Lim and Gan (2005) has shown that the highest number of vascular bundles, with rigid and strong walls are found in the periphery, but the number of vascular bundles not only decreases in number but they also have weaker cell walls towards the middle and core of the oil palm trunk. Inevitably, the higher density OPW from the periphery produced the lowest dust concentration, while the core resulted in the highest dust concentration during the abrasive sanding process.

Comparative Dust Emission Characteristics

Previous industrial studies (Ratnasingam *et al.* 2009, 2011) have shown that workers are exposed to dust exposure levels above the standard 5 mg m^{-3} time-weighted average (TWA) over 8 h in most wood products manufacturing mills in Malaysia. Hence, the use of dust protection gears or dust masks by workers is highly recommended to ensure their health and safety in such working conditions (Saejiw *et al.* 2009).

Table 2. Dust Particle Size Distribution during Abrasive Sanding

Material	Average Density(g/cm^3)	Proportion of Airborne Dust (%) Defined as Particles > 10 µm in Size	Proportion of Respirable Dust (%) Defined as Particles < 10 µm in Size	Dust Particle Size (µm) Distribution in %								
				28	24	20	16	12	8	4	1	0.5
Rubberwood	0.54 (0.021)	95	5	57	12	8	9	9	3	2		
OPW Periphery	0.50 (0.020)	76	24	38	12	10	9	7	10	10	3	1
OPW Middle	0.39 (0.016)	71	29	35	11	10	8	7	13	12	2	2
OPW Core	0.25 (0.013)	68	32	34	10	8	8	8	14	12	3.5	2.5
OPW Middle (Treated)	0.49 (0.017)	75	25	31	13	13	9	9	11	8	4	2
OPW Core (Treated)	0.46 (0.017)	73	27	32	12	10	11	8	12	8.5	4	3.5

Note: Figures in caption refer to standard deviation values.

In the context of the abrasive sanding process of OPW, a much higher level of dust concentration is observed compared to wood materials due to the unique cellular makeup of the OPW, as reported by Frühwald and Akrami (2014). Furthermore, OPW has a tendency to emit higher levels of respirable dust particles, especially the OPW from the lower density, middle and core portions of the trunk, which poses a higher safety and health risk to workers. This is to be expected due to the increased proportion of softer parenchyma tissues in the middle and core of the trunk, which can be easily crushed and scrapped into finer respirable dust during the abrasive sanding process (Ratnasingam *et al.* 2004).

Another notable observation is the fact that the proportion of fine respirable dust particles produced appears to be higher when sanding the treated OPW, although the difference was not statistically significant. Although resin-impregnation increases the strength and stability of the OPW, the harder resin appears to be contributing to a higher emission of fine dust particles, which increases the dustiness of the surrounding air during the abrasive sanding process.

Industrial Implications

This study revealed the dust emission characteristics of OPW and rubberwood. It was apparent that the dust concentration during the abrasive sanding process was related more to the material's density and hardness rather than the stock removal rate. In fact, the dust emission characteristics appear to have a stronger relationship to the anatomical features of the material, as highlighted previously in the report by Ratnasingam and Scholz (2015). The findings from this study also revealed that OPW produced higher dust concentration levels and also a higher proportion of fine respirable dust compared to rubberwood during the abrasive sanding process. Although resin-impregnation improved the density and hardness of OPW, which inevitably improved its strength and stability, the dust emission characteristics of treated OPW was comparable to the untreated OPW, with a significantly higher proportion of fine respirable dust emitted during the abrasive sanding process. The fact that the resin-impregnated OPW produced a higher proportion of fine dust particles was attested by the fact that a higher exhaust velocity was required to ensure compliance with the permissible dust emission level (PEL) (Fig. 4). This higher exhaust air power would inevitably translate into higher energy demand, which in turn would lead to higher machining cost when working with OPW compared to rubberwood. This is obvious due to that the fact that with airborne fine dust, a higher extraction power is required to capture these fine dust particles (Ratnasingam *et al.* 2004). In this context, it was apparent that the OPW abrasive sanding process is more energy intensive, and thus it will pose a significant cost implication on the processing of OPW.

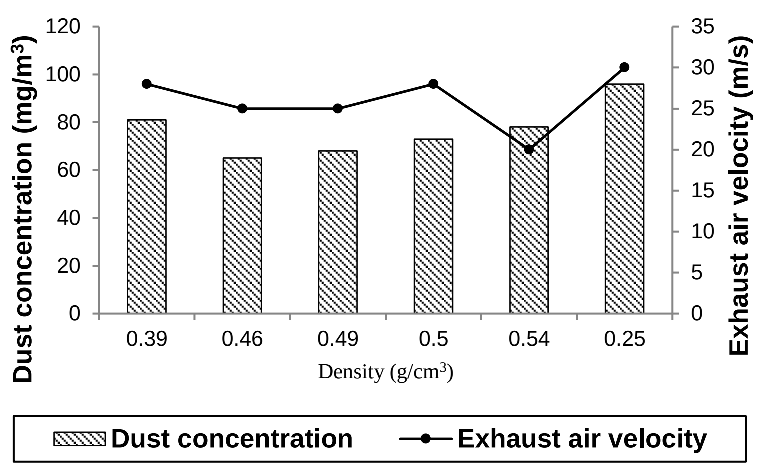

Fig. 4. Comparative exhaust air velocity requirement

Although the resultant dust concentration arising from the abrasive sanding process is related to the stock removal rate (Ratnasingam *et al.* 2004), based on this study it is apparent that the material's anatomical characteristics also influences its dust emission characteristics (Fig. 4). Therefore, the stock removal rate, which is often construed to be directly linked to the material's density, appears to be more influenced by the density variation rather than the average density of the material, as shown in this study.

To establish comparative benchmark dust emission values, a field measurement was conducted at a factory using OPW and rubberwood in their furniture manufacturing operations. Measurements over a week showed that OPW produced almost 1.5 times more dust volume in the abrasive sanding operations compared to that of solid rubberwood, and this amounted to significantly higher exhaust power consumption, which in turn translated into higher cost. In this context, the different dust emission characteristics of OPW must be taken into consideration, if the OPW is to be used successfully utilized in the manufacturing of value-added wood products.

The findings of the study also emphasized the fact that the permissible exposure level (PEL) for dust during the processing of OPW could not be set at the prevailing 5 mg/m^3 based on the 8 h TWA, but it should be much more stringent to protect the workers' safety and health. Further, finer respirable dust particles from the resin-impregnation of OPW may also pose serious health ramifications to the workers' over the long-term. Therefore, an immediate review of the dust exposure standard in the industry is required, while the requirement that all workers wear the necessary dust protective and personal safety gear and masks must be made mandatory. Ultimately, the prevailing dust concentration during the abrasive sanding process is related to the stock removal rate and the cutting speed used, and efforts must be made to minimize the amount of abrasive sanding required in order to help create a more hygienic and comfortable working environment in the manufacturing mills.

CONCLUSIONS

1. Dust emission during the abrasive sanding process of oil palm wood (OPW) and solid wood is influenced by their density variation and hardness and hence, dust emission can be minimized when using higher density stocks.
2. The study also revealed that OPW has significantly higher dust emission levels compared to rubberwood.
3. The OPW from the middle and core portion of the trunk produces a higher proportion of finer respirable dust compared to the OPW from the peripheral portion of the trunk due to significant density variations.
4. The successful use of OPW in value-added products manufacturing will require the formulation and compliance with a much more stringent permissible exposure level (PEL) for dust emission.

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