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AN INVESTIGATION ON THE MECHANICAL PROPERTIES OF TRUNKS OF PALM OIL TREES FOR THE FURNITURE INDUSTRY

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ABSTRACT

High quality wood furniture requires several factors, such as properties of woods, product design, production process and control, which must be considered. Mechanical properties are considered to be some of the most important factors at the stages of product design and material selection. A comparison of mechanical properties between palm oil wood, rubberwood and teak, which are widely used in the furniture industry, is the objective of this study. The base, middle and top samples were cut from palm oil trunks and seven parameters were measured using standard methods and procedures. They included specific gravity, moisture content, bending stress, tensile stress perpendicular-to-grain, hardness, compressive stress parallel-to-grain, and impact stress. The overall results showed that the mechanical properties of palm oil trunk were approximately two times lower than those of teak and rubberwood. Different portions of the palm oil trunk also gave different mechanical properties. It was found that the base of the palm oil trunk gave the lowest modulus of elasticity than the top portion but provided higher hardness than the others. Hence, this study provides essential information on the suitability of palm oil wood for applications in the furniture industry.

Keywords: palm oil wood, rubberwood, teak, mechanical property, furniture.

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INTRODUCTION

Over the years, wood has been utilized for homes and other structures, such as furniture and tools, because of its unique characteristics. Wood furniture is one of the most popular products among a variety of wood utilizations. At the present time, the growing social demands for wood furniture have led to a continuous effort in finding alternative wood resources for the furniture industry. Teak used to be the most popular wood for furniture manufacturing; however, the price of teak has increased rapidly as teak, itself, is considered to be a hard-to-find wood. Rubberwood has become another source of raw material for the furniture industry and has been widely used. Rubber plantations can be found everywhere in the region of southern Thailand and Malaysia. At the same time, palm oil plantation is rapidly growing in both of the mentioned regions and is tending to replace the rubber plantations in many areas. Palm oil tree has proven itself to be an important economic resource in the tropical areas of Southeast Asia, especially in the southern part of Thailand and Malaysia. A wide array of products has been developed from various portions of the palm oil tree. For instance, fibres from fronds of palm oil tree have been used to make particleboards (Lamsuk, 2003); nonetheless, palm oil trunk has not yet been used effectively.

In order to fully utilize the woods, understanding their physical and mechanical properties is vital. All wood is basically composed of cellulose, lignin, hemicelluloses and minor amounts of extraneous materials (5% to 10%) that are contained in a cellular structure (Forest Product Laboratory, 1999). A unique characteristic of wood is depended upon the variations in the characteristics and amount of these components, as well as differences in its cellular structure. Therefore, to use wood to its best advantages and most effectively in furniture industry, physical and mechanical properties of

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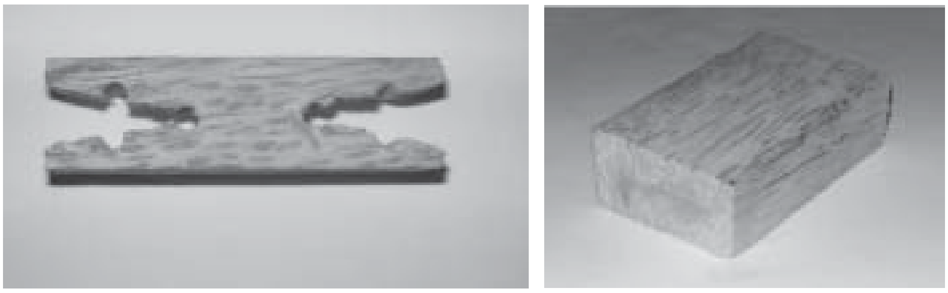
wood must be considered. Many studies have investigated the properties of woods. For example, Sobier *et al.* (2003) investigated the mechanical response of Palmyrah timber which is found in tropical areas around Southeast Asia, particularly, in Sri Lanka. Their studies were undertaken to evaluate the mechanical responses of Palmyrah and to develop estimates of allowable properties. Ratanawilai *et al*. (2003) studied the mechanical properties of medium-density particleboard and medium-density fibreboard (MDF). Also, an investigation on the suitability of using vine pruning as a raw material for particleboards was reported by Ntalos *et al*. (2002). The results showed that partial substitution of wood by vine pruning negatively affects the board properties. Bending strength, internal bond and screw holding strength decreased as the amount of vine pruning particles increased. All mentioned studies have assisted engineers with the design and efficient usage of the timber. Hence, to effectively utilize palm oil wood, especially palm oil trunks, its mechanical properties have to be characterized. Samples were cut from palm oil trunk and tested corresponding to testing standards. The main objective of this study was, therefore, to investigate the mechanical properties of palm oil trunk and compare them to the properties of teak and rubberwood. The suitability of using palm oil wood in the furniture industry was presented. As an alternative material to rubberwood and teak, palm oil tree trunks may help to relieve the intensive cutting of the forest and provide additional income source for palm oil agriculturists.

MATERIAL AND METHODS

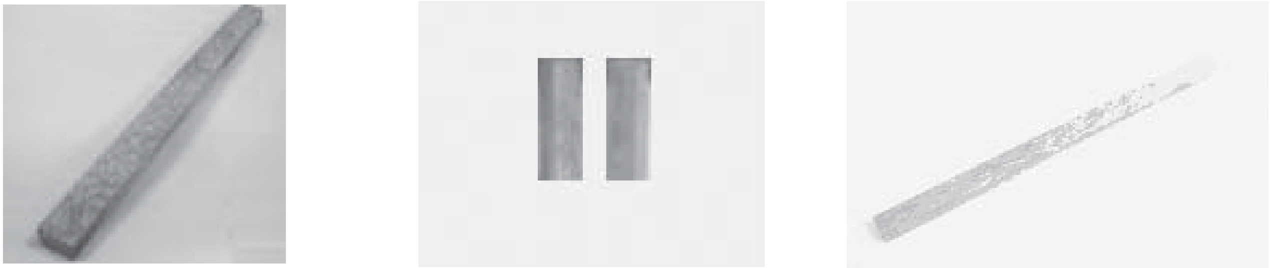
Wood Materials

As trees are subjected to constantly changing environment, such as moisture, soil conditions and growing space during its growth, the properties of the wood derived from them may vary considerably. In this study, 20-year-old palm oil trees from plantation areas in the southern part of Thailand were selected as the substrates. Each of five felled trees was approximately 10 m in height and 0.5 m in diameter. Trunks from each tree were sawn into three portions: base, middle and top, for the mechanical tests. The same parts from each tree were air-seasoned to equilibrium moisture content prior to sample preparations for each of the appropriate mechanical property tests according to standards belonging to the American Society for Testing and Materials (ASTM), the British Standards (BS), and the Thai Industrial Standards (TIS). Test samples shown in *Figure 1* were dried in a kiln at 105°C for 24 hr in order to reduce the moisture contents to approximately 10%-12%. Mechanical properties were subsequently measured.



Tensile test

Hardness test



Bending test

Compressive stress parallel to grain

Impact test

Figure 1. The samples of palm oil trunk for mechanical tests.

Mechanical Tests

Seven tests were conducted in an effort to determine some of the mechanical properties that would be of interest to an engineer in the design stage of wood furniture. Five test samples were used for each of the tests. The seven mechanical tests conducted include the following:

Moisture content, weight and specific gravity (TIS 497-2526). Test samples were milled to 20 mm x 20 mm x 20 mm, dried in the kiln at 105°C for 24 hr to reduce moisture content to a standard 10%-12%. The moisture content was measured using a moisture meter (Testo 606).

Bending test (BS 373). For the bending test, samples with dimensions of 20 mm x 20 mm x 300 mm test were used. An applied load was placed on the sample and increased by 20 kg stepwise. The test was completed when one of the conditions was reached: (a) the specimen was broken, (b) the applied load was less than 10% of the maximum measured force, or (c) the deflection at the middle of the specimen reached 600 mm.

Tensile stress perpendicular to grain (ASTM D3500). Test samples were 20 mm x 20 mm x 70 mm. The V shapes at both ends of each sample were inserted into the upper and lower claw grips of the tensile testing machine. Loading was applied in the direction perpendicular-to-grain until the sample was broken.

Hardness test (ASTM D143). Test samples were 50 mm x 50 mm x 70 mm. The modified Janka hardness test was used to measure the load required to embed one-half of an 11.28 mm (0.444 inches) diameter ball into the sample.

Compressive stress parallel-to-grain (ASTM D3501). Test samples were 15 mm x 15 mm x 60 mm. Loading was applied in the direction parallel to grain of the sample until it was broken.

Impact stress (ASTM D143). Test samples were 20 mm x 20 mm x 300 mm. In this test, a hammer of given weight was dropped upon a beam from successively increasing height until rupture occurred or the beam deflected 152 mm (6 inches) or more.

RESULTS AND DISCUSSION

The test results are shown and discussed in this section. Average values of five replications of the specific gravity (G) test, the bending test, the compressive test, the tensile test, the hardness test, and the transverse impact test are tabulated in *Table 1*.

TABLE 1. MECHANICAL PROPERTIES OF VARIOUS WOODS

Mechanical properties	Hard-wood (teak)*	Medium-hard wood (rubber-wood)**	Soft wood (palm oil wood)					
			Base		Middle		Top	
			Average	Std	Average	Std	Average	Std
Specific gravity (12% moisture content)	0.64	0.70	0.51	0.09	0.45	0.05	0.38	0.06
Bending Test								
- Modulus of elasticity (kg cm^{-2})	1.04E+06	9.60E+04	2.90E+04	1 920	4.63E+04	2 147	5.37E+04	4 604
- Proportional limit stress (kg cm^{-2})	665	600	335.2	21.6	308.8	7.4	286.2	9.8
- Modulus of rupture (kg cm^{-2})	1 023	973	475.4	12.9	437.5	4.6	384.6	18.3
- Energy of rupture (kg-cm cm^{-3})	1.9	2.4	0.52	0.01	0.34	0.01	0.28	0.01
Tensile stress perpendicular-to-grain (kg cm^{-2})	23	28	10.53	0.62	8.57	0.14	6.41	0.30
Compressive stress parallel-to-grain (kg cm^{-2})	505	478	210.6	15.2	190.6	7.5	308.3	21.4
Hardness test (kg)	510	532	198.5	8.9	161.0	8.2	113.0	8.5
Transverse impact test								
- Total energy absorbed (kg-m)	1.7	2.9	0.75	0.11	0.55	0.05	0.99	0.04

Sources: * Visutitepakul (1997); ** Tepaya (1998).

Specific Gravity

Specific gravity is an excellent indicator of the amount of substance contained in a piece of wood. The substance of which wood is composed of is actually lighter than water. Therefore, a dry piece of wood floats in water, and it is evident that part of its volume is occupied by cell cavities and pores. Variations in the size of these openings and in the thickness of the cell walls cause some species to have more wood substance per unit volume than others, thus giving it higher specific gravity. In this study, it was found that the specific gravity of the base (0.51) was higher than that of the middle (0.45) and the top (0.38) part of the palm oil trunk, implying that the base had more wood substance per unit volume than the other parts. Nevertheless, specific gravity values also reflect the presence of gums, resins and extractives, which contribute little to mechanical properties.

TABLE 2. EFFECT OF LOAD ON THE DEFLECTION UNDER BENDING TEST

Load (kg)	Deflection, Y (cm)		
	Base	Middle	Top
0	-	-	-
20	0.16	0.13	0.11
40	0.28	0.25	0.20
60	0.42	0.39	0.30
80	0.64	0.56	0.45
88.4 (base)/83 (middle)/ 82.4(top)	0.88	0.65	0.53
% increase comparing to the base	-	25.55	39.37

Bending Test

To determine strength and deflection of wood in the design stage of furniture, the result of the static bending test is required. *Table 2* summarizes the deflection of palm oil trunk at the base, middle and top. The data was also plotted in *Figure 2* and shows that after increasing the amount of loading by 20 kg in each step, the base part was found to have the highest deflection of 0.878 cm at the maximum load of 88.4 kg. Also, it was found that there was a significant difference in the deflection of the base and the top of the trunk by about 40%. This can be explained by the high specific gravity of the base of the trunk, as shown in *Table 1*. Therefore, it gave the highest deflection and could absorb more load than the other parts of the trunk.

From the bending test, we could also determine the modulus of elasticity, proportional limit stress, modulus of rupture and energy of rupture. The modulus of elasticity implies that deformations produced by low stress are completely recoverable after loads have been removed. When loaded to higher stress levels, plastic deformation or failure occurred. Based on the results in *Table 1*, it was found that the modulus of elasticity of the top part was the highest compared to the middle and the base part of the palm oil trunk. *Figure 3* shows that the modulus of elasticity values for teak and palm oil wood are significantly different. It indicates that teak provided higher stiffness than the other woods because of its high modulus of elasticity.

The proportional limit stress is the maximum stress at which stress is directly proportional to strain. *Figure 3* also shows that the base gave the

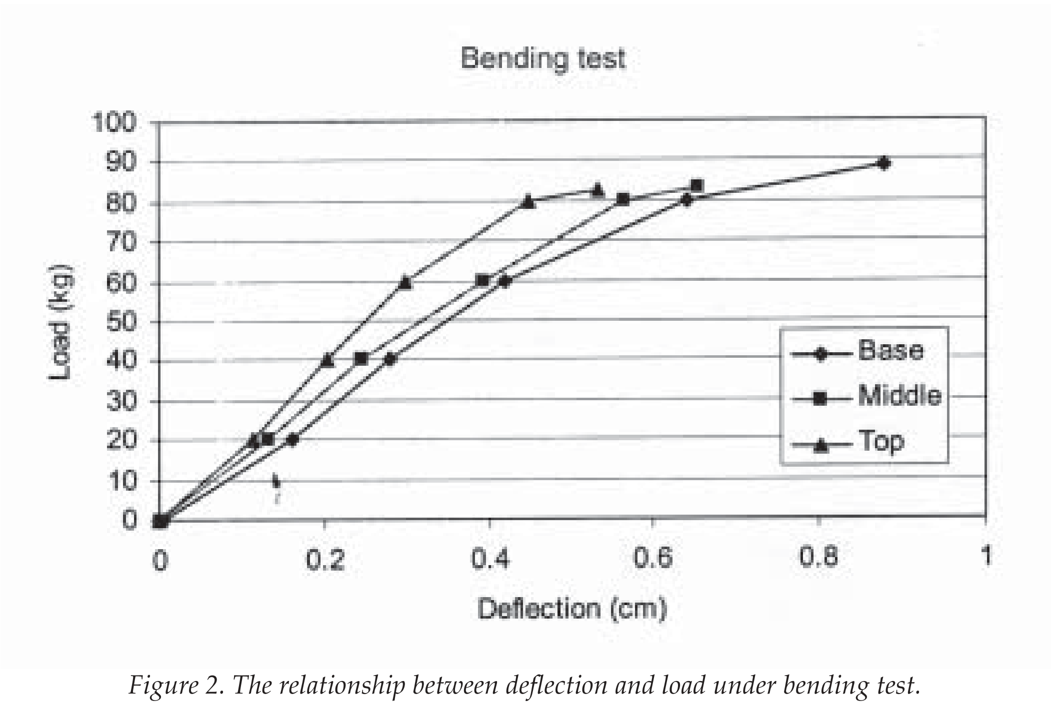


Figure 2. The relationship between deflection and load under bending test.

highest value of 335.2 kg cm^{-2}, whereas the top gave the lowest value of 286.2 kg cm^{-2}. The values of the modulus of rupture and the energy of rupture also ranked in the same order as the proportional limit stress from base to top, with values of 475.4, 437.5 and 384.6 kg cm^{-2} and 0.52, 0.34, and 0.28 kg-cm cm^{-3}, respectively, as shown in *Figure 4*. The modulus of rupture reflected the maximum load carrying capacity of the member in bending and was proportional to the maximum moment borne by the specimen. As a result, the data indicated that the base part gave the highest strength among the three portions of the palm oil trunk, but was still lower than that of the teak and rubberwood by approximately 54% and 51%, respectively.

Tensile Stress Perpendicular to Grain

The resistance of wood to forces acting across the grain that tends to split a member is called tensile stress perpendicular to grain. The data is useful in term of determining the mechanical connected timber joint for furniture industry. Among the samples of palm oil trunk, the highest tensile stress perpendicular to grain of the base part as 10.53 kg cm^{-2} was observed as shown in *Table 1* and *Figure 5*. However, it was lower than the tensile stress of teak (23 kg cm^{-2}) and rubberwood (28 kg cm^{-2}) about 54% and 62%, respectively. Thus, utilizing palm oil trunk as a part of furniture has to be carefully selected.

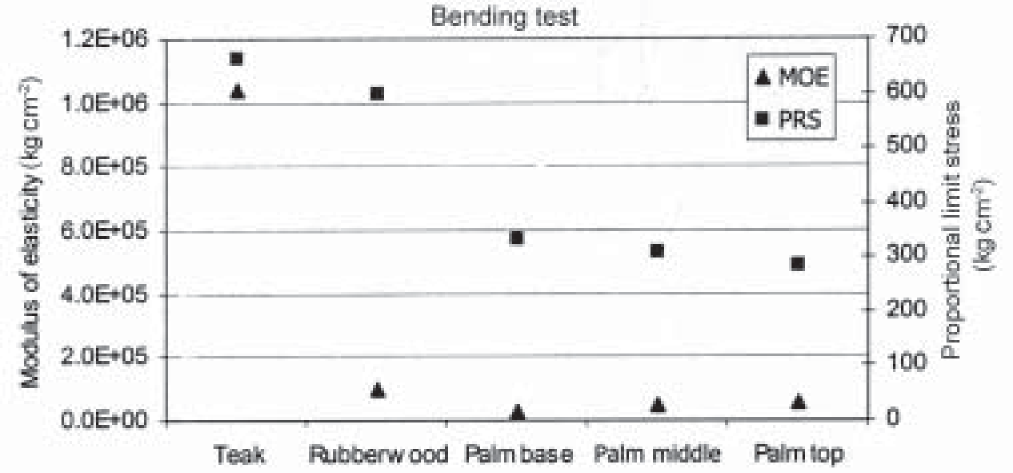


Figure 3. Modulus of elasticity and proportional limit stress of various woods.

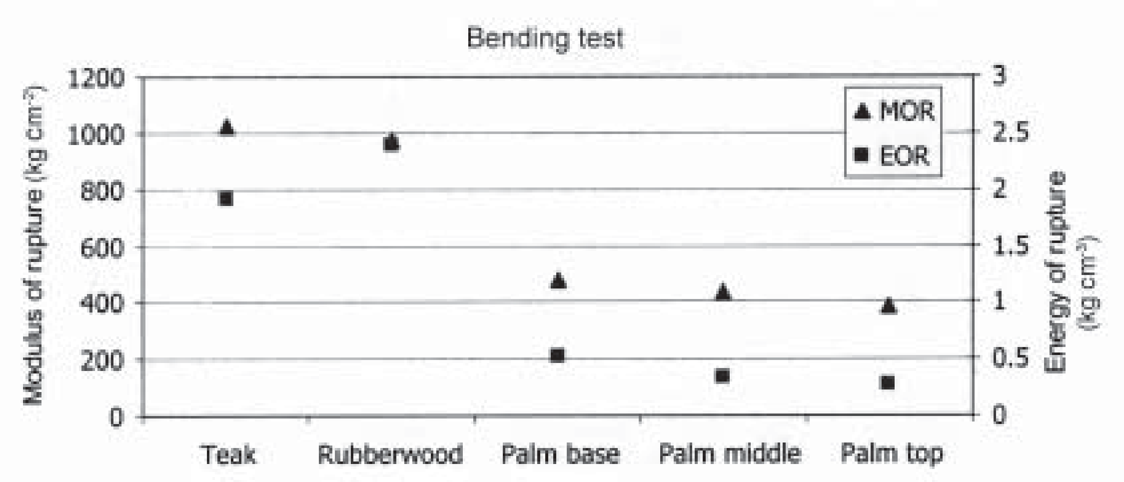


Figure 4. Modulus of rupture and energy of rupture of various woods.

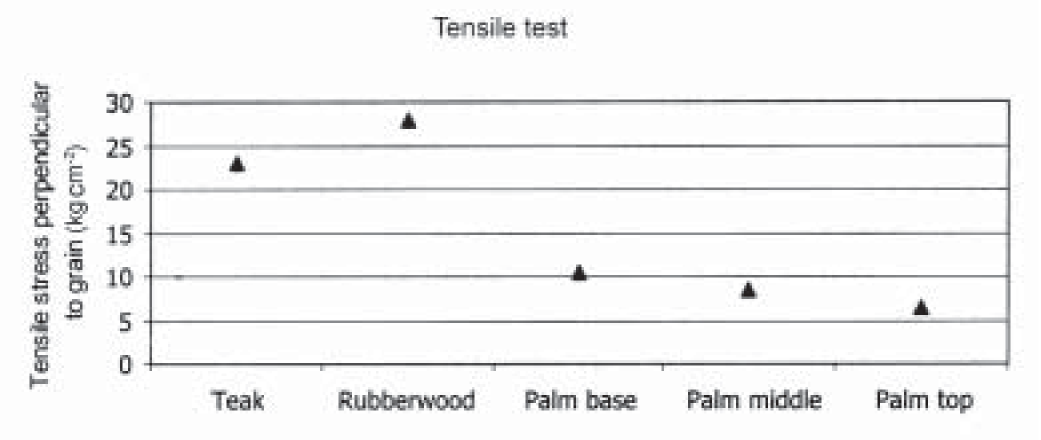


Figure 5. Tensile stress perpendicular to grain of various woods.

Compressive Stress Parallel-to-Grain

Compressive stress parallel-to-grain is defined as the maximum stress sustained by compression of a specimen parallel-to-grain with the specimen having a ratio of length to smallest dimension of less than 11. The results showed that the highest compressive stress for palm oil trunks was observed at the top part at 308 kg cm^{-2} (see *Table 1* and *Figure 6*), whereas the compressive stress of teak and rubberwood were 505 and 478 kg cm^{-2}, respectively. It is often found that many parts of furniture are loaded in term of compressive stress parallel-to-grain; hence, this kind of comparison data should be helpful in the design of furniture.

Hardness Test

Hardness, generally defined as resistance to indentation using a modified Janka hardness test, is measured by the load required to embed a 11.28 mm (0.444 inch) ball to one-half its diameter. Hardness tests were conducted on both sides of the sample and the averaged measured values were calculated. The highest value of hardness was found at the base to be 198.5 kg, whereas the lowest value was obtained at the top as shown in *Table 1* and *Figure 7*. As expected, the hardness of palm oil trunk was observed to be lower than the hardness of teak (510 kg) and rubberwood (532 kg), which was lower by approximately 61% and 63%, respectively. The higher value of hardness provided a better resistance to scratch. Therefore, among the three parts of palm oil trunk, the base part showed the best resistance to scratch and is the most appropriate for making furniture when a hard-top surface is required.

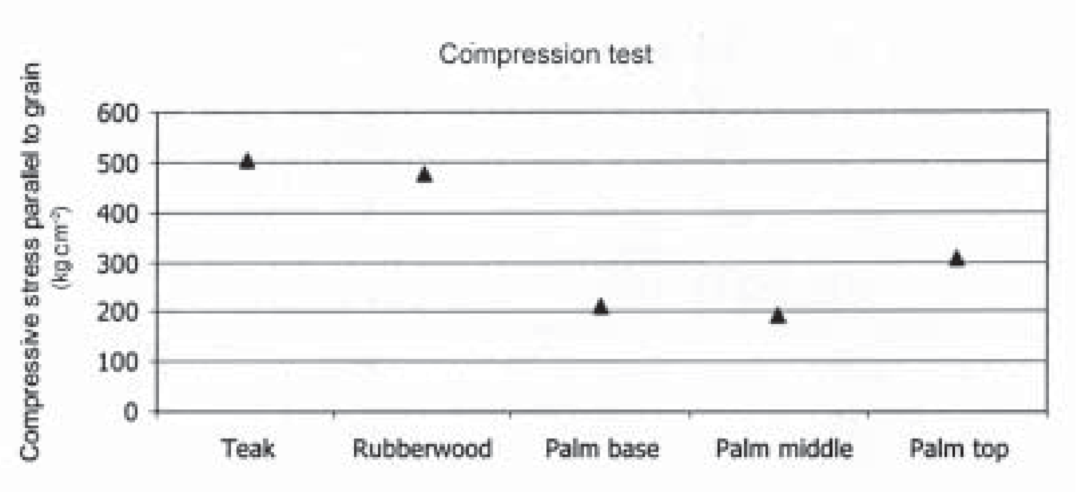


Figure 6. Compressive stress parallel to grain of various woods.

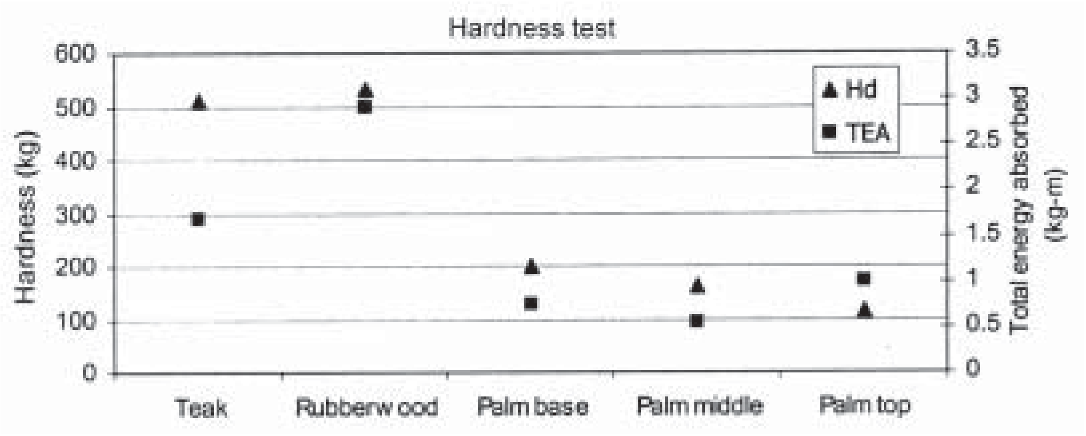


Figure 7. Hardness and total energy absorbed of various woods.

Transverse Impact Test

For the impact bending test, a hammer of given weight is dropped upon a beam from successively increasing heights until rupture occurs or the beam deflects 152 mm (6 inches) or more. The height of the maximum drop, or the drop that causes failure, is a comparative value that represents the ability of wood to absorb shocks up to its proportional limit. *Table 1* and *Figure 7* show that the highest total energy absorbed for palm oil trunks was found at the top with a value of 0.99 kg-m, whereas the total energy absorbed for teak (1.7 kg-m) and rubberwood (2.9 kg-m) were higher by about 42% and 66%, respectively. Even though results imply that the top part was the toughest and could absorb more energy than the other parts of the trunk, it still was not as tough as hard wood and medium-hard wood.

CONCLUSION

Mechanical properties of palm oil trunks were investigated in this study. After comparing among the three portions of palm oil trunks: the base, the middle and the top, it was observed that the highest values of modulus of elasticity, modulus of rupture, tensile stress perpendicular-to-grain and hardness were obtained from the base of the trunk. On the other hand, the highest values of compressive stress parallel-to-grain and total energy absorbed under transverse impact test were found at the top part of the trunk. Most of the highest mechanical properties of the palm oil trunk were found to be approximately two times lower than the values obtained from teak and rubberwood. As a result, careful selection of the appropriate section of the palm oil wood is necessary in order to fully utilize it in furniture making. More importantly, its mechanical properties must correspond to the functions and the requirement of that particular piece of furniture. This study, therefore, provides an important knowledge of the mechanical properties of palm oil wood trunks, which is essential in the utilization of palm oil wood in the furniture industry. Furthermore, the findings can be used as a base knowledge for further strengthening purposes of the wood for wider range of applications.

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