Mechanical Properties of *Cocos nucifera* Wood Planted Around Mt. Merapi, Yogyakarta

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Abstract

This study presented test results of mechanical properties of *Cocos nucifera* wood that were planted around Mt. Merapi, Yogyakarta. The test specimens were obtained from trees that had been exposed to pyroclastic flow during the 2010 volcanic eruption as indicated by dark colour of the outer bark. Test set-up was designed according to ASTM D143-94 and the mechanical properties, which are determined based on the lower 5% exclusion limit, were bending strength, shear strength, dowel bearing strength and compressive strength. Results of the specific gravity measurement showed significant variation of specific gravity between the inner part (close to the pith) and the outer part (far from the pith) in a cross-section. Since mechanical properties generally depend upon specific gravity, it was decided to divide the wood specimens into two groups: specimens from the inner part and specimens from the outer part. Most of the mechanical properties of wood specimens from the inner part, except for bending strength, were found to be much lower than E10 grade of the Indonesian National Standard (SNI). Hence it is not recommended for any structural use. In the case of wood specimens from the outer part, their mechanical properties were as follows: bending strength 83.66 MPa; shear strength parallel to grain 4.41 MPa; dowel bearing strength parallel to grain 40.65 MPa; dowel bearing strength perpendicular to grain 25.88 MPa, compressive strength parallel to grain 37.89 MPa; and compressive strength perpendicular to grain 7.48 MPa. It seemed that the wood specimens from the outer part had excellent mechanical properties especially in bending, but their shear strength is extremely low.

Keywords: *Cocos nucifera*, mechanical properties, Mt. Merapi, strength grade.

Introduction

Yogyakarta is blessed by the presence of Merapi, the most active volcano in the world. According to Wikipedia.org (November 2010), the small eruption would occur in every two or three years, while the period of big eruption is ten to fifteen years. As a periodic natural phenomenon, Merapi eruption fertilizes the soil and grows various kinds of tree besides releasing very high quality sands and stones. The area of forest in Mt. Merapi is about 14,325.99 ha and the majority belongs to the Indonesian government (Sutikno *et al*. 2007). Furthermore, they reported that tree species with very high population are Pinus (*Pinus merkusii*) and Sengon (*Paraserianthes falcataria*). Just after the Merapi eruption in October 2010, a team was dispatched to the affected areas to investigate the possible construction of temporary shelters as well as to decide the building materials should be used for the shelter. One of the most important findings is shown in Figures 1 and 2. Figure 1 shows a failure of steel structure, which is located about 4 km from the mountain, due to pyroclastic flow during the Merapi eruption. This emphasizes the fact that steel structures posse potential disaster when they are exposed to elevated temperature. Pyroclastic flow can reach temperature of about 1000°C (Wikipedia.org). A few days exposed to acid volcanic ash leads to rapid corrosion of the fractured steel elements. However, the team was surprised that many tress were standstill though pyroclastic flow passed them as indicated by the colour of their outer bark (Figure 2). Further investigation on mechanical properties of *Cocos nucifera* which has experienced pyroclastic flow was proposed.

Figure 1. Failure of steel structure exposed to pyroclastic flow.

Figure 2. Tree planation exposed to pyroclastic flow during the Merapi eruption 2010.

Cocos nucifera has been well known traditionally for its high bending strength. They are commonly used as purlins of a roof structure or as beams of a floor system. Previous study have shown that *Cocos nucifera* can be classified as E14 grade of the Indonesian National Standard (SNI 2002) with MOE equals to 14,478 MPa and density of 0.52 gr/cm^3 (Chauf 2009).

Materials and Methods

Two trunks of *Cocos nucifera* that have experienced pyroclastic flow were used in this study. Each trunk was divided into three parts having 3 m length per each. Only trunk of the bottom part was considered in this study. The trunk was cut in longitudinal direction to obtain around four lumbers with the thickness of 50 mm as shown in Figure 3. All the lumbers were kept in a storage room for several weeks until the moisture content reached 15%. Changes of moisture content of the lumbers were continuously monitored.

Figure 3b shows that the 50 mm thick lumber still has good physical appearance even though it was exposed to pyroclastic flow. No charring was found after removal the outer bark. Minimum heat penetration from the outer bark to the pith was probably due to short exposure period and high moisture content of the trunk as the eruption was occurred in raining season.

Test of mechanical properties was carried out according to ASTM D143-94. Dimension of clear specimens are illustrated in Figure 4 where only four mechanical properties were considered: compression strength parallel to grain and perpendicular to grain; bending strength; shear strength parallel to grain; dowel bearing strength parallel to grain and perpendicular to grain. In addition to those mechanical properties test, measurement of moisture content and specific gravity were also carried out.

Average moisture content of the specimen was 14.9% and average specific gravity was 0.90 and 0.51, for wood section located far and near the pith, respectively. Wood section near the pith has brighter colour than the wood section far from the pith. As wood strength in general depends on specific gravity (Brock 1957; Dwianto *et al*. 2008), wood specimens were further grouped into inner part (near the pith) and outer part (far from the pith) for each mechanical property test.

Test of mechanical properties was carried out at the Structural Engineering Laboratory of Gadjah Mada University. Besides the average (F_{avg}) and standard deviation (STD) values, the characteristic strength which is determined based on the lower 5% exclusion limit was analyzed (Abdurachman *et al*. 2009). They can be derived from this following equation:

$$F_{5\%} = F_{avg} - 1{,}645\,STD \tag{1}$$

$$STD = \left(\frac{\sum f^2 - \left[(\sum f)^2/n\right]}{n-1}\right)^{1/2} \tag{2}$$

$$F_{avg} = \frac{\sum f}{n} \tag{3}$$

where f and n is strength data and the number of sample, respectively. Desch *et al*. (1980) considered the lower 1% exclusion limit as the characteristic strength instead of the lower 5% exclusion limit, which are generally used in many timber engineering standards. In the Equation 1, the characteristic strength does not take into account the influence of loading duration factor and wood defects such as knots and grain orientation.

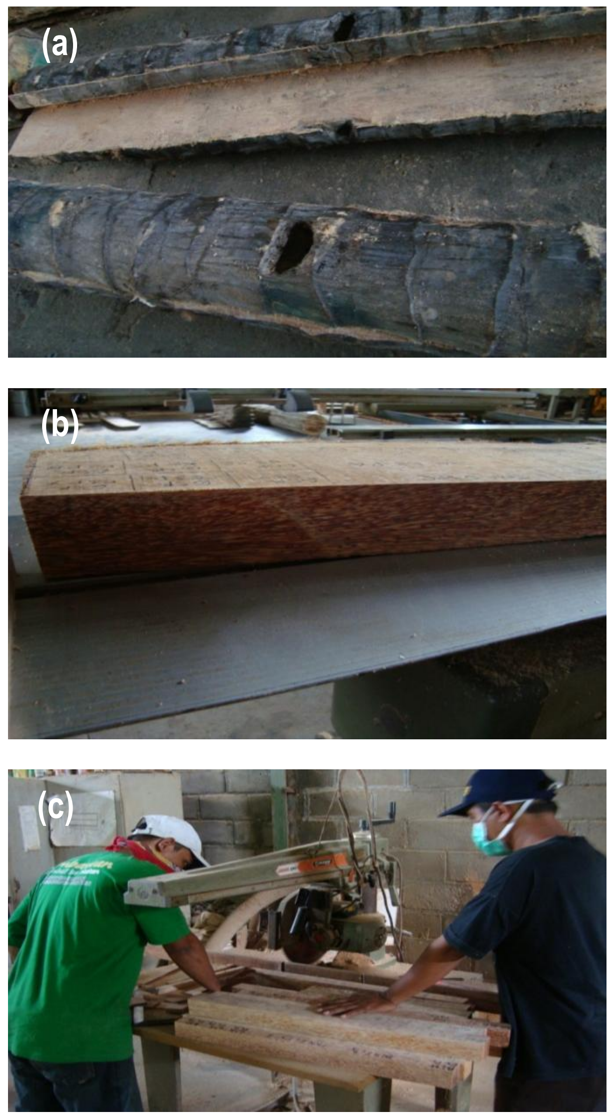

Figure 3. Fabrication of clear specimens to ASTM D143-94: (a) *Cocos nucifera* exposed to pyroclastic flow; (b) 50-mm thick lumber; and (c) Fabrication of clear specimens.

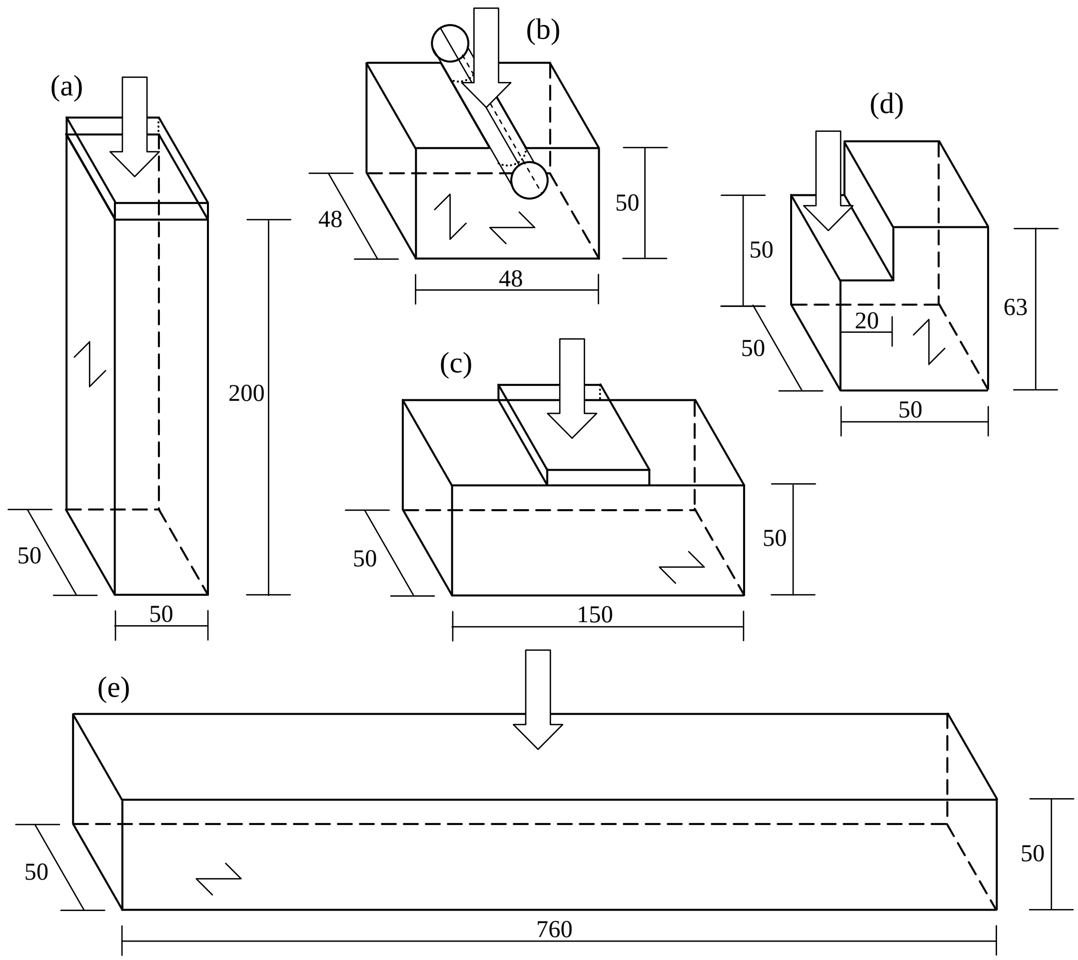

Figure 4. Clear specimens: (a) Compression parallel to grain; (b) Dowel bearing parallel to grain; (c) Compression perpendicular to grain; (d) Shear; and (e) Bending.

Results and Discussions

Some photos of the mechanical property tests are shown in Figure 5 where failure of each specimen was attained less than 5 min. Except for compression strength perpendicular to grain test, most of the tests gave brittle failure. Table 1 and 2 summarize the mechanical properties of the outer part and inner part of *Cocos nucifera*, respectively, obtained from the test. The mechanical properties of the outer part are significantly higher than those of the inner part. Around 4.8 times in compression strength parallel to grain; 2.35 times in shear strength parallel to grain; 2.23 times in bending strength; and 1.6 times in compression strength perpendicular to grain.

Table 1 shows that wood specimens from the outer part have characteristic strength as follows: Compressive strength parallel to grain (F_{c0}) 37.89 MPa; Compressive strength perpendicular to grain (F_{c90}) 7.48 MPa; Bending strength (F_b) 83.66 MPa; and Shear strength parallel to grain (F_{v0}) 4.41 MPa. It seemed that the wood specimens from the outer part had excellent mechanical properties especially in bending and compression parallel to grain, but their shear strength is extremely low. Therefore, serious attention must be paid in design of shear members. Table 1 also shows the dowel bearing strength with two difference steel-dowel diameter (12 and 8 mm) where dowel bearing strength of 8 mm steel-dowel are greater than that of 12 mm steel-dowel. Brittle failure after reaching the maximum dowel bearing strength was observed in all specimens, which is relatively rare in most wood specimens under loading parallel to grain.

In the case of wood specimens from the inner part, their characteristic strengths were found to be much lower than E10 grade of SNI (2002), except for bending strength. Thus it is not recommended to use them for any structural members.

The characteristic strengths given in Table 1 or 2 are subjected to reduction factors such as reduction factors related to wood defects or loading duration. To consider the effect of both loading duration and wood defects, Desch *et al*. (1980) proposed a safety factor of 2.25 for most mechanical properties except compression parallel to the grain where the factor is 1.4. In the SNI (2002), these reduction factors are treated separately. Regarding wood

Table 1. Mechanical properties of the outer part of *Cocos nucifera* (MPa).

Strength properties	Number of specimen	F_{avg}	STD	$F_{5\%}$
F_{c0}	20	54.29	9.97	37.89
F_{c90}	10	16.25	5.33	7.48
F_b	8	95.97	7.48	83.66
F_{v0}	24	6.18	1.07	4.41
F_{e0}*	8	53.82	8.00	40.65
F_{e0}**	8	61.23	7.84	48.33
F_{e90}*	8	41.31	9.38	25.88
F_{e90}**	8	47.45	8.61	33.28

Table 2. Mechanical properties of the inner part of *Cocos nucifera* (MPa).

Strength properties	Number of specimen	F_{avg}	STD	$F_{5\%}$
F_{c0}	15	24.82	10.33	7.82
F_{c90}	8	10.04	3.32	4.58
F_b	5	45.49	4.85	37.51
F_{v0}	17	3.21	0.81	1.87

Table 3. Average strength properties of the outer part of *Cocos nucifera* (Chauf 2009).

Density (gr/cm^3)	Moisture content (%)	F_{c0} (MPa)	F_b (MPa)	F_{v0} (MPa)
0.52	15.05	18.80	48.96	10.15

Figure 5. Photos of the test: (a) Dowel bearing test – outer part specimen; and (b) Failure of shear parallel to grain specimen.

defects, the SNI (2002) allows only three groups: grade A, B and C with a reduction factor of 0.80, 0.63 and 0.5, respectively. While loading duration factor equals to 1.0 for short duration loads such as wind or earthquake and it equals to 0.6 for permanent load (dead weight).

Compared with the mechanical properties of the outer part of *Cocos nucifera* shown in Table 3 (Chauf 2009), the characteristic strengths summarized in Table 1 are far more superior in compression strength parallel to grain (F_{c0}) and bending strength (F_b). This finding leads to a conclusion that short exposure period of pyroclastic flow did not give negative effect on the characteristic strengths of *Cocos nucifera*. Further study especially on chemical composition of the wood specimens should be carried out to obtain more explanation related to these increased mechanical properties.

Conclusions and Suggestions

This study examined the mechanical properties of *Cocos nucifera* planted in Mt. Merapi areas that has experienced pyroclastic flow during Merapi eruption 2010. Results of physical observation and clear specimen tests indicated that heat penetration during exposure to pyroclastic flow was a minimum and gave no negative effect on the characteristic strength of the specimens. The test data showed excellent characteristic strength of wood specimens from the outer part (far from the pith) especially in bending strength and compression strength parallel to grain. In contrast, the characteristic strength of wood specimen near the pith is extremely low and shall not be used for structural application.

Acknowledgment

The authors wish to express sincerely gratitude to TVOne Television Broadcasting Company for the financial support provided to this project.

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