In Search of Substitution Material for Traditional Javanese Wooden Houses

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Abstract

Many Javanese traditional timber structures have been destroyed by major earthquake. The impact of the disaster demanded a deeper finding on timber materials for repairing and reconstructing. To understand the mechanical property of timber for Javanese timber house, compression test were carried out for radial and tangential direction. Traditional joint construction use mortise and tenon system that stress yield in intersection occurred. Compression property and partial compression property is quite important for traditional joint construction. Especially, the mechanical properties against density of tropical timber were studied.

In this paper, authors showed substitute materials for Javanese timber houses from tropical timber. A total of 288 specimens made from six tropical timber species were tested. All of tropical timber specimens showed strong relationship between Young's modulus (E) and density. There was clear trend that the smaller density indicated the smaller Young's modulus. Jati, Nangka, Sonokeling, Ketepeng and Acacia had similar increasing mechanical properties, while in the case of specimen Falcata, it mechanical properties were stagnant. The bigger density indicated the bigger Young's modulus. Acacia and Ketepeng have MOE and density nearby Jati. Both of specimens has also similar tendency of mechanical properties with Jati.

Key words: Javanese timber structure, traditional joint system, tropical timber, mechanical properties.

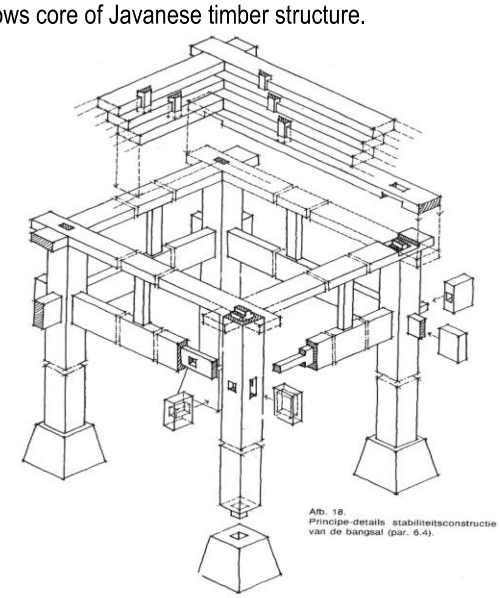
Introduction

Recent earthquake hit Java Island-Indonesia has caused many damaged buildings, including Javanese wooden houses. Javanese timber structures of Joglo type is the most complicated and sophisticated roof type in terms of the construction and techniques of Javanese wooden houses. The Joglo use Teak wood (*Tectona grandis*) or Jati wood (local name) as the primary construction material for both the building's structure and the ornaments. The houses use a knock down construction method, using mortise and tenon.

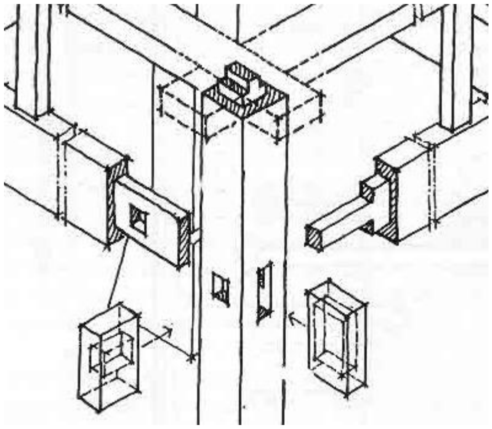
The repairing or reconstruct of damaged house need same material (Teak wood), in relation with strength, durability, and prestige. Reconstruction must be carried out using same material that comply the local wisdom and the minimum standards of structural strength. Prihatmaji (2010b), summarize the work carried out to characterize physical properties, mechanical properties and chemical properties to identify an original material for Manggarai traditional building in Flores, Indonesia. If the original materials are not usable due to damage, they should be substituted with suitable equal material (Jogja Heritage Society 2007). Now, to provide Jati wood in sufficient size is difficult, because of limited quantity and very expensive price (Yahmo 2007). Search of substitution material is needed in consideration with mechanical properties of Teak wood. In this paper, comparison of substitution material for Javanese wooden house was carried out associated with mechanical properties of tropical timber.

Javanese Timber Structures

Javanese timber structures have been built by using typical timber character traits integrated together. Thick column and beam, joints of column-tie beam, and bracket complexes are typical examples of the character traits, and are the most important structural elements (Prihatmaji, 2010a). The columns are set on top of base stones, with column mortise embedment in stone tenon. At the top of the columns there are bracket complexes to support heavy roof, and beams are used to tie columns together at couple levels of height using clamp system with wooden keys. Figure 1 shows core of Javanese timber structure.



1a. The whole part of core structure (Leerdam1995).



1b. Detail of joint construction

Figure 1. Core structure in Javanese wooden house (Leerdam 1995).

When the structure deformed by earthquake, embedment in joint occurs, and generate force moments to all jointing component.

Material and Methods

In this study, six kinds of tropical timbers were tested and they were chosen by purposive random sampling method. According to tropical timber grading issued by PIKA-Pendidikan Industri Kayu Atas, Semarang (1981), there are 5 grades timber in terms of strength. In this study, five timbers were representing second grade and one type of timber represented third grade. The species were 6 hardwoods: Jati (*Tectona grandis*), Nangka (*Artocarpus heterophyllus*), Sonokeling (*Dalbergia latifolia*); Ketepeng (*Terminalia catappa*); Akasia (*Acacia mangium*); Falcata (*Paraserianthes falcataria*).

The specimens came from several small timber markets in Yogyakarta and they were chosen from the available material. Especially for Falcata, they taken from Okinawa, Japan. Altogether, 288 structural size timber specimens were compression tested, full and partial test in radial direction and tangential direction. Both of test type were representing configuration of traditional joint construction as shown in Figure 2. Figure 3 shows the scheme of compression test and it was executed by compression test set-up as shown in Figure 4.

Type A indicates full compression test and type B indicates partial compression with end distance of 0.5, 1 and 1.5 times of the height. End distance indicates type of traditional joint construction. The larger end distance cause higher rotation property due to stress distribution to the extended part of tenon, as shown in Figure 2. All of specimens before test were put on chamber and set on temperature of 22ºC and humidity of 57%. After test, all specimens were oven dried on temperature of 105ºC). Moisture content of specimens was obtained from the difference between weights after and before drying. Density was achieved from the weight after chamber divided by volume.

The compression test used Instron 100 kN. The compression load was applied on the specimen in full contact test and on the partial contact test. For partial contact test, steel plate of 40 mm in width was put on the center of specimen. The compression loading protocol was static loading with speed of 0.5 mm/min. It was applied until deformation of 3 mm.

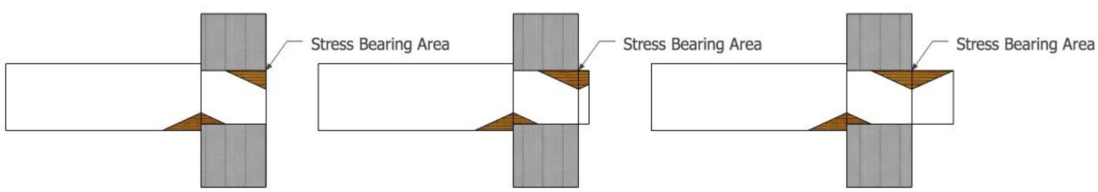


Figure 2. Basic type of joint construction and stress distribution against rotation.

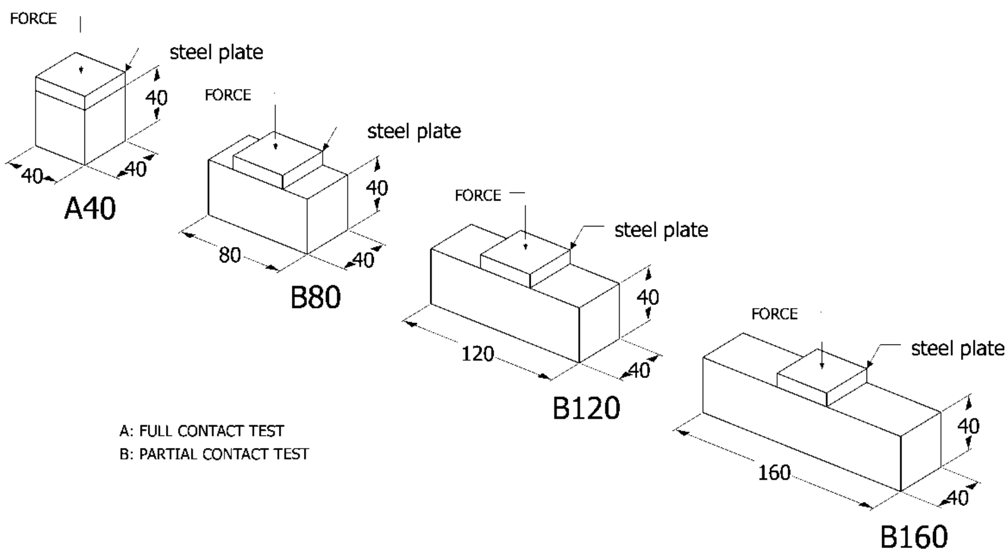


Figure 3. Scheme of compression test.

Figure 4. Compression test set-up of tropical timber specimens.

Results and Discussion

Mechanical Properties

Tables 1 and 2 show mechanical properties of specimens obtained by the test. The values shown in the table are the mean value of each 6 duplicates.

Mechanical Properties and Density

Figures 5, 6, 7 and 8 shows comparison of mechanical properties (Young's modulus and yield stress) between each material, in each test radial and tangential directions are shown.

In these figures, it can be seen that Young's modulus (E) has strong relationship with density, in proportion to the second power of density. Falcata has lowest both Young's modulus and density and Sonokeling has highest one. Otherwise, Acacia has Young's modulus and density second lowest. Ketepeng has MOE and density second highest.

From Figure 5a, it can be seen that Jati has higher density than Nangka, but the Young's modulus of Nangka higher than Jati. Figure 5b show that Jati has Young's modulus and density higher than Acacia and Nangka. In Figure 6a, Jati has density higher than Nangka and it's Young's modulus lower than Nangka. Figure 6b shows that Jati has density much higher than Nangka, but the Young's modulus of Jati is little bit lower than Nangka. As it is seen from these figures, Young's modulus and density of Acacia is lowest than Jati and Nangka.

Figures 7 and 8 shows the comparison of yield stress in each test of radial and tangential direction between each material.

In these figures, yield stress showed proportional relationship between densities as well. Falcata is lowest for yield stress and density and Sonokeling is highest one. Ketepeng has yield stress and density is second highest and Acacia is second lowest for yield stress and density.

From Figure 7, it can be seen that species of Nangka has highest yield stress, although Jati has highest density. Figures 8 shows species of Nangka has highest yield stress than Jati and Acacia.

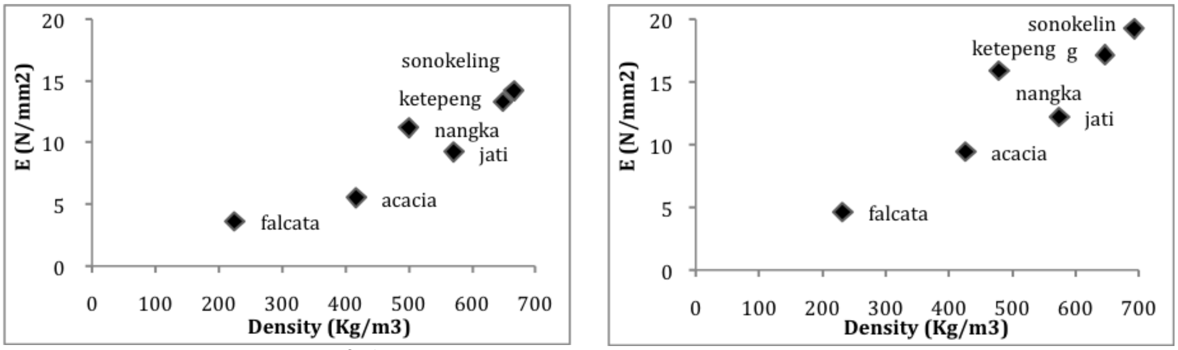
In order to seek substitute materials for Javanese wooden structures, similar mechanical properties of Jati were in search. In these figure, mechanical properties of Acacia and Nangka located in nearby Jati.

Table 1. Mechanical properties of specimens tested in radial direction.

Name of Species	Type of specimen	E (N/mm^2)	Yield stress (N/mm^2)	Max Stress (N/mm^2)	Density (Kg/m^3)	Moisture Content (%)
Jati	A40	427.11	9.26	10.67	571.91	0.119
	B80	781.95	16.72	18.76	590.46	0.126
	B120	786.29	12.22	15.90	574.92	0.130
	B160	556.83	14.11	17.11	572.94	0.133
Nangka	A40	493.09	11.21	12.08	500.27	0.112
	B80	661.60	16.27	18.05	487.46	0.114
	B120	744.91	15.91	18.38	479.31	0.115
	B160	542.03	17.40	19.16	487.99	0.119
Sonokeling	A40	692.94	14.20	15.96	666.65	0.123
	B80	725.45	18.45	21.77	676.14	0.126
	B120	986.15	19.25	23.28	692.77	0.125
	B160	956.98	18.17	22.44	685.51	0.126
Ketepeng	A40	662.61	13.33	14.48	649.34	0.144
	B80	724.59	17.17	19.98	651.39	0.147
	B120	934.69	17.16	20.68	646.84	0.144
	B160	948.49	17.81	21.60	657.44	0.145
Falcata	A40	275.60	3.65	3.75	225.12	0.138
	B80	228.16	4.97	5.76	239.62	0.117
	B120	203.78	4.65	5.63	232.10	0.125
	B160	201.19	4.64	5.55	228.96	0.125
Acacia	A40	297.57	5.49	5.91	417.34	0.157
	B80	542.35	7.71	8.92	413.53	0.173
	B120	685.22	9.48	11.34	426.76	0.174
	B160	677.13	9.60	11.38	414.62	0.171

Table 2. Mechanical properties of specimens tested in tangential direction.

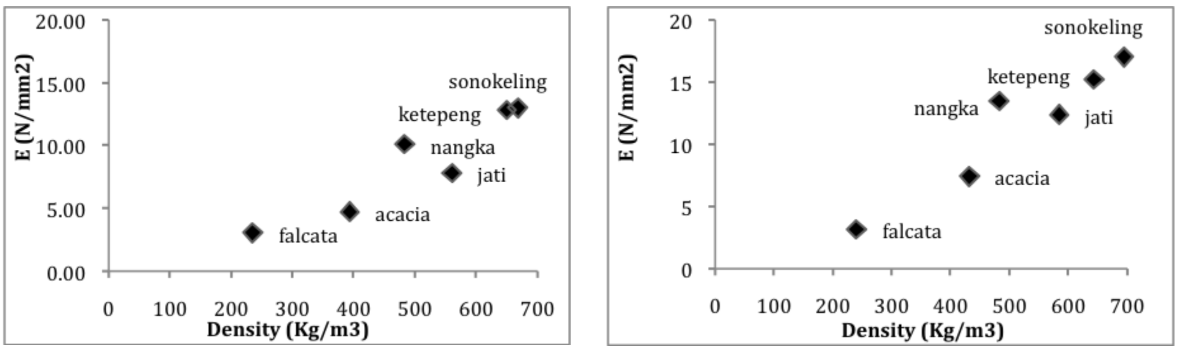
Name of Species	Type of specimen	E (N/mm^2)	Yield stress (N/mm^2)	Max Stress (N/mm^2)	Density (Kg/m^3)	Moisture Content (%)
Jati	A40	248.92	5.40	6.19	560.42	0.119
	B80	570.43	13.95	16.18	592.61	0.130
	B120	539.89	12.40	14.84	584.44	0.128
	B160	483.35	12.15	14.60	569.13	0.134
Nangka	A40	356.66	10.10	10.85	483.16	0.111
	B80	621.37	15.05	16.93	511.43	0.115
	B120	525.36	13.49	15.40	482.23	0.113
	B160	569.02	15.93	18.33	495.79	0.118
Sonokeling	A40	574.28	13.00	14.57	667.75	0.122
	B80	535.52	15.70	18.42	680.68	0.121
	B120	838.86	17.03	20.85	693.68	0.125
	B160	763.74	15.88	19.55	661.49	0.125
Ketepeng	A40	662.25	12.82	14.23	649.64	0.144
	B80	776.77	15.67	18.77	640.15	1.857
	B120	695.92	15.21	18.81	642.85	0.145
	B160	797.19	15.75	19.53	661.32	0.146
Falcata	A40	165.48	3.02	3.16	234.78	0.138
	B80	182.32	3.77	4.58	229.64	0.122
	B120	159.13	3.19	3.96	239.63	0.124
	B160	130.14	3.37	4.06	230.07	0.123
Acacia	A40	255.98	4.70	5.18	393.64	0.171
	B80	368.72	6.70	7.75	418.33	0.170
	B120	470.51	7.43	8.96	431.59	0.173
	B160	418.04	7.21	8.63	438.32	0.170



a. Full contact test of 40 mm

b. Partial contact test of 120 mm

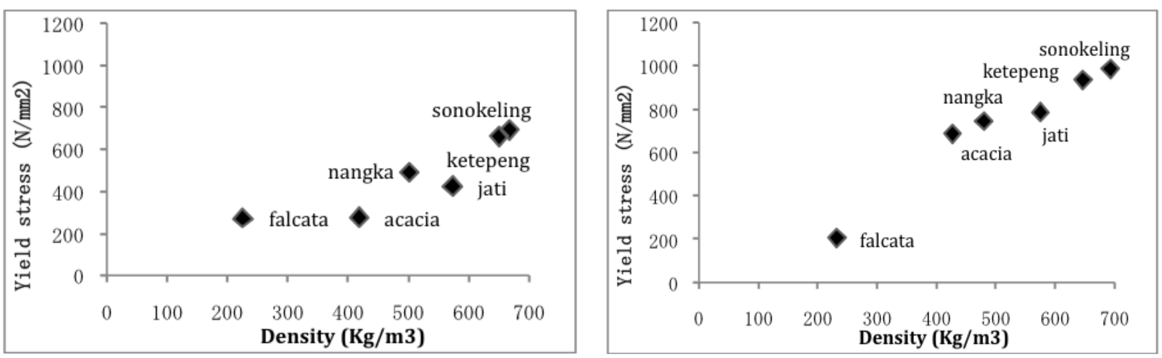
Figure 5. Comparison of Young's modulus in relation to the density between each material in radial direction.



a. Full contact test of 40 mm

b. Partial contact test of 120 mm

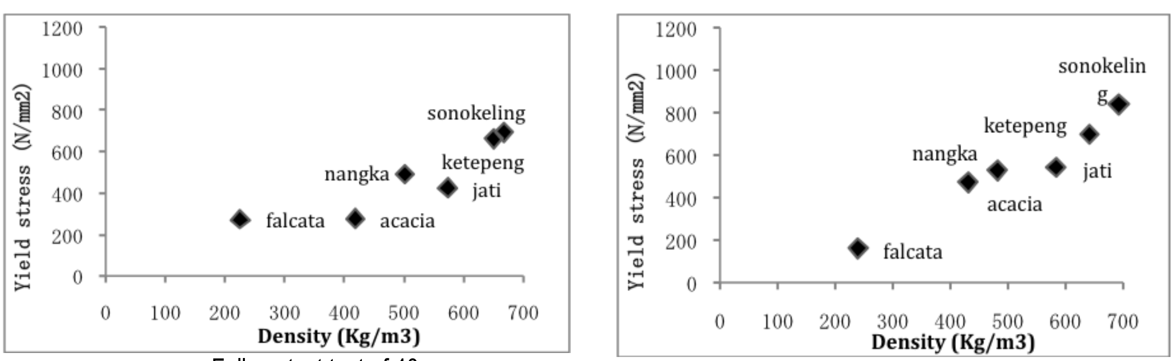
Figure 6. Comparison of Young's modulus in relation to the density between each material in tangential direction.



a. Full contact test of 40 mm

b. Partial contact test of 120 mm

Figure 7. Comparison of yield stress in relation to the density between each material in radial direction.



a. Full contact test of 40 mm

b. Partial contact test of 120 mm

Figure 8. Comparison of yield stress in relation to the density between each material in tangential direction.

Stress and Strain

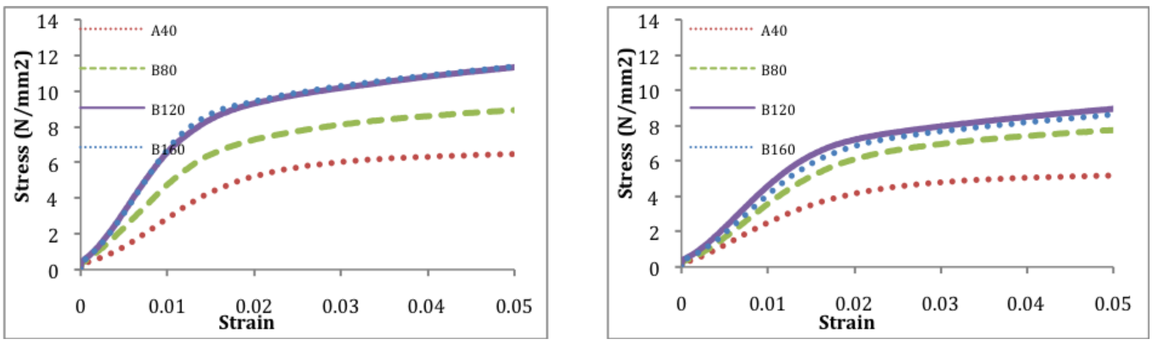
Figures 9, 10, and 11 show the stress and strain relationship for Acacia, Jati and Nangka. The stress and strain relationship of three species was taken from all of specimen (A40, B80, B120 and B160) in both directions as a representative result.

From Figure 9a, in general it can be seen an increase trend of load carrying capacity against strain. Full compression specimen showed elasto-plastic behaviour, while partial compression specimens showed growing tendency even after yield strength. Figure 9b shows that the end distance contributes to yield stress obviously in tangential direction. From these figures, yield stress average of radial and tangential direction is quite similar.

Figure 10 shows that the end distance influence indistinct to yield stress of Jati. But, still it can be seen a trend of increase compared with full compression result.

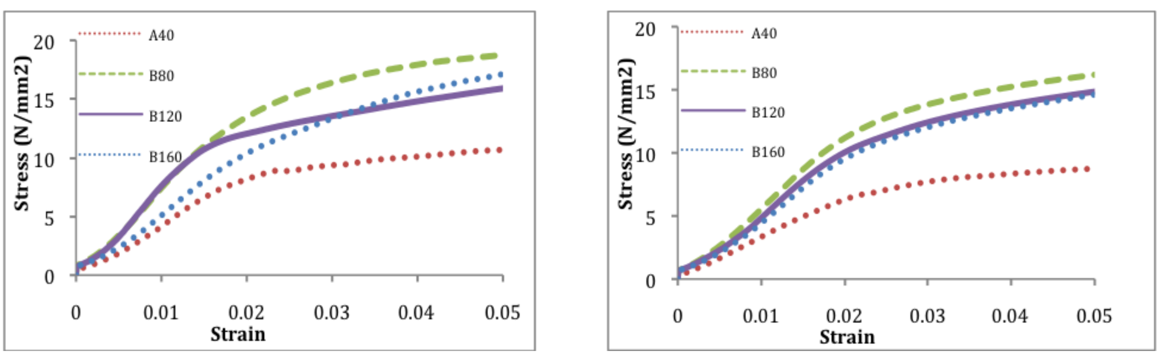
In Figures 11a and 11b shows that the yield stress of Nangka has obvious increase on both modulus and strength in full contact test and partial contact test. In these figures, it can be seen clear trend of increase of yield stress.

According to the discussion in above, it can be said that Acacia and Nangka have stress nearby Jati. Both of specimens has also similar tendency of mechanical properties with Jati, and can be chosen as substitute material for Jati in terms of mechanical property.



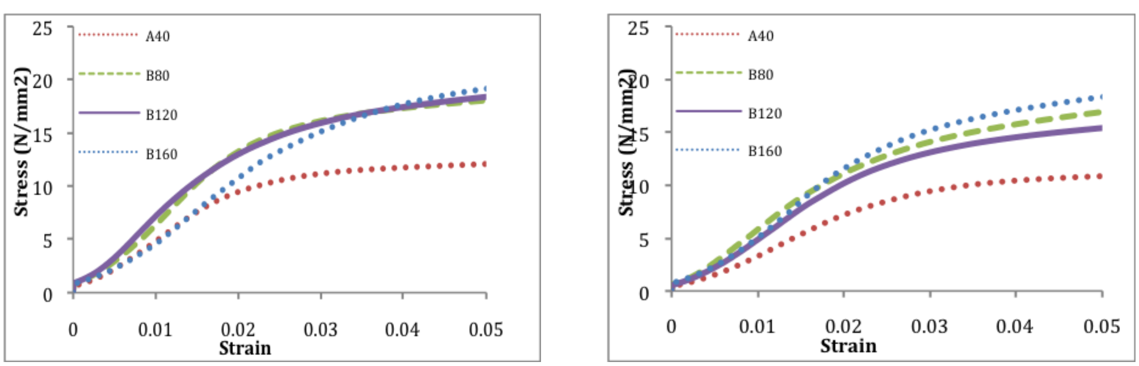
a. In radial direction b. In tangential direction

Figure 9. Stress and strain relationship of Acacia.



a. In radial direction b. Partial contact test - 120 mm

Figure 10. Stress and strain relationship of Jati.



a. In radial direction b. In tangential direction

Figure 11. Stress and strain relationship of Nangka.

Comparison of MOE in Partial Compression Test between Each Material

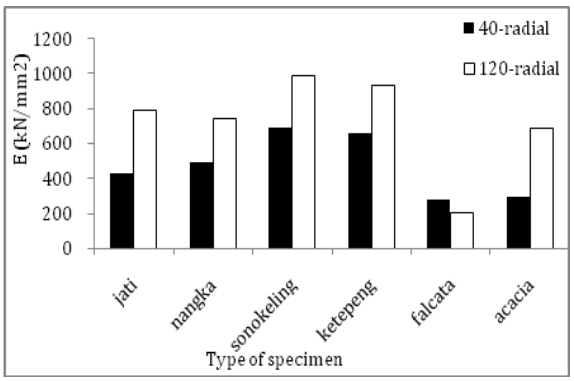
Figure 12 shows comparison of Young`s modulus in full and partial compression test between each material. In these figures, in radial direction test, Acacia has a ratio of more than or similar twice between full contact test and partial test, while in Nangka and Jati specimens has small ratios. Jati specimens has a ratio of more than or similar once in both directions.

It can be seen Falcata specimen has same or even smaller MOE from full contact test (40 mm) and partial contact test (120 mm). The others specimen has more than or equal to once.

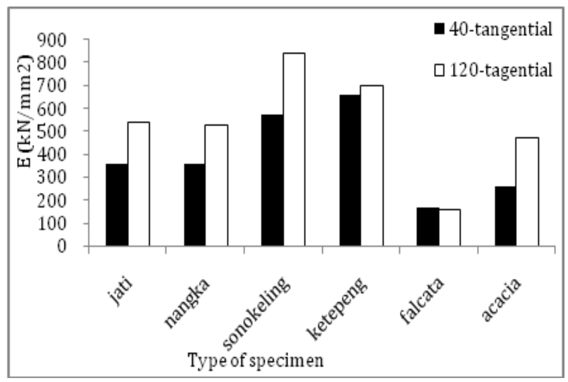
Comparison Ratio of Increase Young's Modulus and Yield Stress

Figure 13 shows comparison of increase ratio of Young`s modulus and yield stress of three species. The increase ratio means value of MOE or yield stress from specimens A40 against specimens B120. From these figures in below, it can be seen trend of ratios increase.

From these figures, it can be seen that the similar increase tendency was observed in the case of strength; on the other hand, there was difference between species on increase ratio of Young's modulus. Acacia showed highest increase ratio reached to around 2 times, while Nangka showed smaller trend. This was because of the difference of the shear modulus and bending modulus, which work to transmit compression stress to the extended portion of wood.

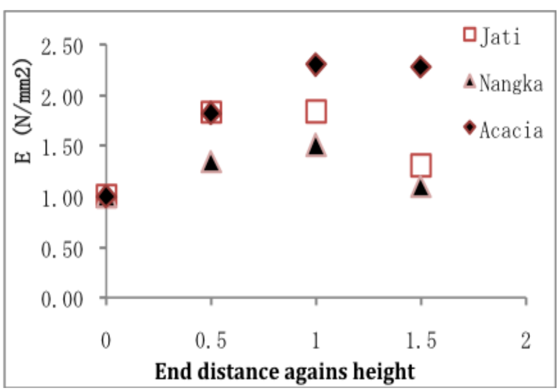


a. In radial direction

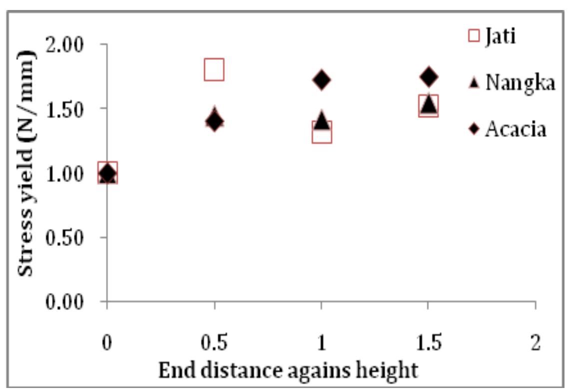


b. In tangential direction

Figure 12. Comparison of mechanical properties in partial compression test between each material.



a. In radial direction



b. In tangential direction

Figure 13. Comparison ratio of increase Young`s modulus and yield stress.

Conclusions

The compression test for six tropical timbers has been done and it was found that some comparisons have strong relation to their mechanical properties. From the result of compression test, the following conclusions can be drawn:

1. In all of tropical timber species, MOE show the strong relationship with densities. There were clear tendency that the smaller density indicates the smaller MOE. Falcata wood has lowest mechanical property and Sonokeling wood is highest in radial direction. All of species tested has around one and half ratio for MOE increase when it has sufficient the end distance, except Falcata.
2. Acacia, Jati, and Nangka has similar trend of increasing Young`s modulus and yield stress. The stress and strain of them indicates that increase trend is clear to show up. Jati, Acacia and Nangka has show clearly significant tendency of increase ratio of MOE. Both of specimens has also equal tendency of mechanical properties with Jati.
3. In considering result of MOE, Yield stress and density, Acacia, Jati and Nangka has similar mechanical properties. Acacia and Nangka will be recomended to substitute Jati for Javanese wooden house reconstruction.

Acknowledgment

The study was funded by the Directorate of Higher Education; Ministry of National Education Republic of Indonesia under DIKTI Scholarship Batch 3a.

References

Leerdam, B.F.V.1995. Architect Henry Maclaine Pont, Een Speurtocht-naar-het-Wezenlijke van de Javaanse Architectuur. Dissertation at TechnischeUniversiteit Delft.

JHS (Jogja Heritage Society). 2007. Kotagede Heritage District, Yogyakarta, Indonesia: Home Owners's Conservation Manual, UNESCO Bangkok-UNESCO Jakarta. p 121-145.

PIKA (Pendidikan Industri Kayu Atas). 1981. Mengenal Sifat-sifat Kayu Indonesia dan Penggunaannya. Penerbit Kanisius, Yogyakarta.

Prihatmaji, Y.P.; A. Kitamori; K. Komatsu. 2010. The Impact of Tongue and Gulls Connection System for Earthquake Resistance for Javanese Wooden House. Proceeding of the World Conference on Timber Engineering, Trentino, Italy. p 415 (II).

Prihatmaji, Y.P.; K. Aryati; I. Suprijanto. 2010. Reading on Lembur Wood (*Pterocarpus indicus*) in Manggarai Traditional Building, Flores (Mbaru Niang Mbowang). Proceeding of National Seminar of MAPEKI, Bali.

Yahmo, I. 2007. Current State Of Wooden Architecture In Indonesia, Asian Forum for Wooden Architecture, Tokyo, Japan. p 2.

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