Softening Behaviour of Indonesian Wood Species

Wahyu Dwianto, Ikuho Iida, and Kazuya Minato

Abstract

This paper deals with softening behaviour measurements of Indonesian wood species by static bending tests. Wood samples with a size of 110mm (R) x 10mm (T) x 4mm (L) were bending tested in air-dry at 20°C and 65% relative humidity (RH), in water saturation at 20°C, and in water saturation at 80°C to know the decreasing of modulus of elasticity (MOE) and modulus of rupture (MOR) due to moisture content (MC) and both moisture content and temperature (MCT) changes. The wood samples represented Randu (*Bombax ceiba*. L) as the lowest specific gravity, i.e. 0.27 to Lamtoro (*Leucaena glauca* (Willd) Benth) as the highest specific gravity, i.e. 0.81. The three-point static bending test was carried out by a mechanical testing machine with a load capacity of 100kgf, loading deflection speed of 5mm/min, a span distance of 80mm at a room with a temperature of 20°C and 65% RH for air-dry wood samples, and that for wet wood samples were conducted in a water bath at 20°C (change in MC) and 80°C (change in MCT), respectively. MOE and MOR increased linearly with specific gravity regardless of wood species. On the other hand, maximum deflection did not correlate with specific gravity for any MCT conditions. The relative MOE and MOR which were calculated in wet 20°C to air-dry were affected from hardly to strongly depending on the wood species. Meanwhile, they decreased extremely when saturated in water at 80°C regardless of wood species. The relative MOE and MOR due to the change in MC or MCT was independent of specific gravity, as well. Furthermore, chemical compositions of the wood species were analysed to clarify the main factors that affected the decreasing of MOE and MOR due to MC and MCT changes. The results showed that the percentage of lignin and hemicelluloses in each wood played an important role in decreasing the static bending properties. Relative MOE and MOR decreased with increasing lignin and hemicellulose contents. It can be concluded that the hygrothermal properties of lignin and hemicelluloses significantly affect the changes of elastic and strength properties of wood in softening conditions.

Keywords: softening behaviour, static bending tests, MOE, MOR, specific gravity, chemical compositions.

Introduction

Various studies on wood softening techniques and its behaviour by heating in wet conditions, such as immersing in hot water, microwave heating (Norimoto and Gril 1989), and steaming (Makinaga *et al*. 1997) have been investigated. Wood softening techniques were also found in the smoke heat treatment process (Nomura 2002) to minimize the damage caused by twisting or collapse, log peeling process of raw material for plywood, or in the treatment process of wood chips into fibre for pulp raw material (thermo-mechanical pulping).

It has widely known that amorphous polymers of wood and other lignocellulose materials partly changed from a glassy state into a rubbery condition and experience a decrease in stiffness and strength when heated in wet conditions at certain temperatures (Hillis and Rozsa 1978). The behaviour depended on the glass transition temperature of cellulose, hemicellulose, and lignin (Goring 1963), where this did not occur in dry conditions. Hillis and Rozsa (1978) reported that hemicellulose glass transition temperature of fresh wood was around 70°C ~ 80°C, and that of lignin was between 80°C ~ 100°C. The addition of steam time will further reduce the transition temperature.

Some researchers have conducted difficult measurements to determine changes of stiffness (rigidity) and strength properties of wood in softening conditions, such as by thermal compression technique (Goring 1963), vibration technique (Urakami and Nakato 1966), elastic shear modulus (Atack 1972), torsional loading (Hillis and Rozsa 1978), stress relaxation (Dwianto *et al*. 1999), or creep test (Takahashi *et al*. 2002). The measurement can be done more easily by static bending tests. Iida (1989) has investigated changes in the elastic properties and strength of 24 Japanese wood species by the static bending tests. The results showed that there was a difference in the average ratio of flexural strength, fracture strength, and maximum deflection between softwood and hardwood with the increasing moisture content and temperature. He considered that the hygrothermal properties of lignin greatly influence the changes in the flexural strength and fracture strength of the woods due to hygrothermal effects.

In the drying and manufacturing of wood and wood-based materials, variation of mechanical properties accompanied with the changes of moisture content and temperature is extremely important concerning the quality and yield of the products. However, the information for mechanical properties has scarcely been obtained not only for major tropical wood species but also abundant lesser-used and fast-growing tropical wood species. Especially when we intend to use those tropical woods, it may be essential to clarify the dependencies of mechanical properties on moisture content and temperature.

This study evaluated the decrease in mechanical properties of 15 Indonesian wood species caused by changes in moisture content and temperature through static bending tests. Furthermore, chemical compositions of the wood species were analyzed to clarify the main factors that affect the decreasing of MOE and MOR due to moisture content and temperature changes and to empirically determine the relationship between the chemical compositions and the static flexural properties of the softening conditions. Some parts of these results have been published (Sudijono *et al*. 2004), but the wood species used in this experiment were supported by analysis of their chemical compositions to determine the factors causing their softening behavior.

Materials and Methods

Materials

Fifteen (15) wood species used in static bending tests and their respective air-dry specific gravities were Randu (*Bombax ceiba*. L; 0.27), Albizia (*Falcataria* molucana (L.) Nielson; 0.31), Angsana (*Pterocarpus indicus* Jacq.; 0.45), Durian (*Durio zibethinus* Murray; 0.45), Mindi (*Melia azedarach* (L); 0.46), Kecapi (*Sandoricum koetjape* (Burm.f.) Merr; 0.48), Manii (*Maesopsis eminii* Engl.; 0.50), Acacia (*Acacia mangium* Willd; 0.52), Agathis (*Agathis damara* (Lambert) Rich; 0.53), Bacang (*Mangifera foetida* Lour; 0.58), Nangka (*Arthocarpus heterophylla* Lamk; 0.64), Mahogany (*Swietenia mahaghony* (L) Jacq; 0.65), Puspa (*Schima wallichii* (DC) Korth; 0.70), Rubber (*Hevea brasiliensis* (Willd.ex.ALJuss) Muell.Arg; 0.71), and Lamtoro (*Leucaena glauca* (Willd) Benth; 0.81). The wood samples represented Randu (*Bombax ceiba*. L) as the lowest specific gravity, i.e. 0.27 to Lamtoro (*Leucaena glauca* (Willd) Benth) as the highest specific gravity, i.e. 0.81.

The test sample size was 110mm (R) x 10mm (T) x 4mm (L). To get homogenous conditions, all the wood samples were water-saturated at room temperature for 12 hours and then were immersed into 80°C water for 3 hours.

Static Bending Tests

The wood samples for the static bending test were divided into 3 conditions, as followed: (1) Air-dry condition at 20°C and 65% relative humidity (RH), (2) Water saturation at 20°C (wet 20°C), and (3) Water saturation at 80°C (wet 80°C) to evaluate the decrease in flexural strength (MOE) and fracture strength (MOR) caused by changes in moisture content (MC) and both moisture and temperature (MCT) factors. The air-dry wood samples were placed in an adjustable temperature and RH room to 20°C and 65% RH, respectively; before equilibrium moisture content. Wet wood samples were immersed in room-temperature water for more than a week after the pre-condition described above. Wood samples of the three conditions were taken from subsequently cut of their transverse direction and 4 repetitions for each condition.

The three-point static bending tests were carried out by a mechanical testing machine with a load capacity of 100kgf, loading deflection speed of 5mm/min, a span distance of 80mm at a room with a temperature of 20°C and 65% RH for air-dry wood samples, and that for wet wood samples were conducted in a water bath at 20°C (change in MC) and 80°C (change in MCT), respectively (Figure 1).

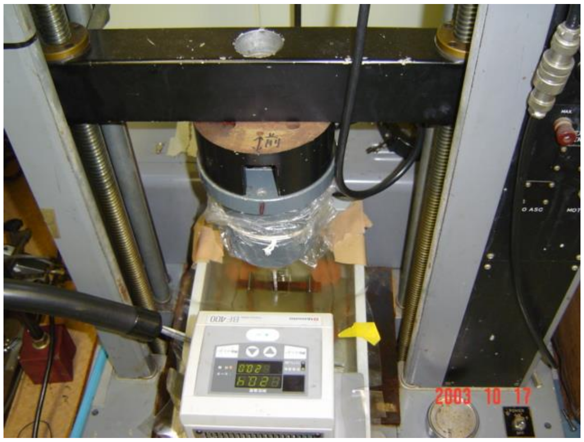

Figure 1. Static bending tests in a water bath.

Chemical Analysis

Chemical composition, including extractive content, α-cellulose, lignin, and hemicellulose, the 15 wood species were analysed by Wise and Klason lignin methods.

Results and Discussion

Mechanical Properties

Figures 2, 3, and 4 show the relationship between the air-dry specific gravity of the 15 wood species to their MOE, MOR, and maximum deflection values, respectively.

The values of static flexural properties test results of all the wood samples show that MOE and MOR increased linearly with increasing specific gravity and laid on a linear regression (Figure 2 and Figure 3). However, maximum deflection values of each wood species in the three conditions were widely fluctuation and were not correlated to specific gravity at any change in MC or MCT (Figure 4). It was probably due to different response of each wood species to MC and MCT changes.

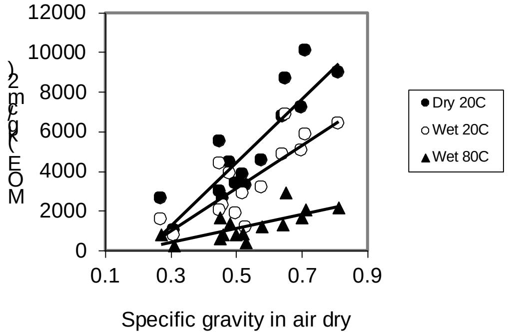

Figure 2. Relationship between MOE and air-dry specific gravity (Sudijono *et al*. 2004).

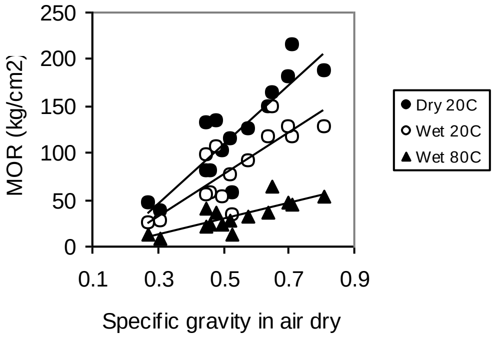

Figure 3. Relationship between MOR and air-dry specific gravity (Sudijono *et al*. 2004).

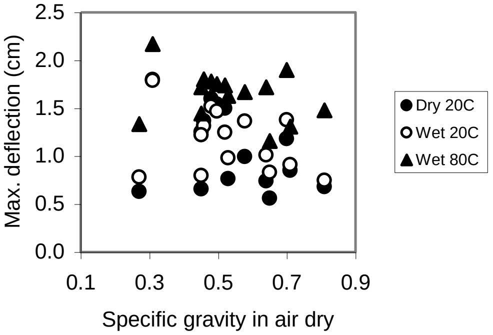

Figure 4. Relationship between maximum deflection and air-dry specific gravity (Sudijono *et al*. 2004).

To understand which wood species have more or less affected by changes of MC and both MCT regardless of specific gravity, relative modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated based on the value in air-dry at 20°C. The decreasing of relative MOE and MOR is shown in Figures 5 and 6, respectively.

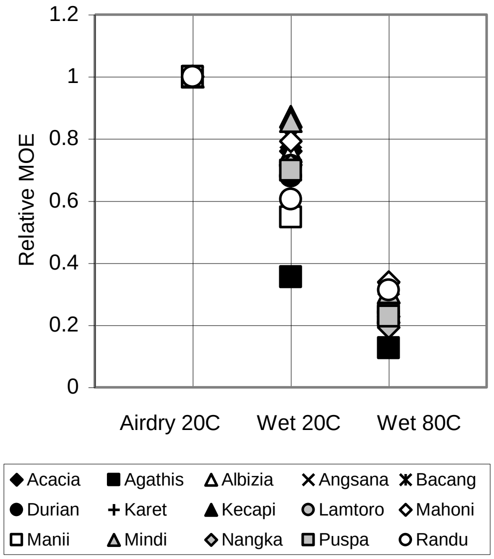

Figure 5. Decreasing of relative MOE due to changing of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C) (Sudijono *et al*. 2004).

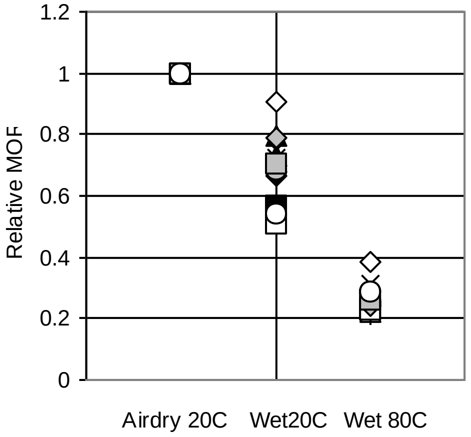

Figure 6. Decreasing of relative MOR due to changing of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C) (Sudijono *et al*. 2004).
Legend: see Fig. 5.

The relative MOE significantly decreased with changes in MC and MCT (Figure 5). The decline in the relative MOE in wet at 20°C caused by changes in MC were very wide and could be separated into the less affected species group (between 0.8 and 0.7), i.e. Mahoni, Acacia, Nangka, Lamtoro, Puspa, and Bacang woods; and the moderate affected species group (between 0.6 and 0.5), i.e. Randu, Karet and Manii woods. However, most of them were strongly affected by changes in MCT. The relative

MOE in wet at 80°C decreased to 0.3 ~ 0.2 as a result of the change in MCT.

Agathis has most affected by changes in MC and MCT. The value of relative MOE decreased to 0.35 in wet at 20°C and fell to 0.12 in wet at 80°C. The decreasing of MOE due to changes of MC and MCT was regardless of specific gravity. For example, the relative MOE of Acacia, which has the same specific gravity as Agathis, has decreased only 0.76 in wet at 20°C, and 0.23 in wet at 80°C. Agathis was the only softwood in this experiment. It was considered that Agathis has a lower softening temperature than that of hardwoods.

The decreasing of relative MOR is shown in Figure 6. It was recognized that Mahoni wood has most resistance against the changes of MC and MCT compared with the other woods. The relative MOR of Mahoni wood only decreased to 0.9 with changes in MC and 0.4 with changes in MCT. The decrease in the relative MOR caused by changes in MC in wet at 20°C for other wood species can be determined and grouped into the moderate affected species group (between 0.8 and 0.65), i.e. Acacia, Nangka, Lamtoro, Puspa, and Bacang woods. Then the most affected species group (between 0.6 and 0.5), i.e. Agathis, Randu, Karet, and Manii woods. However, most of the relative MOR were decreased to 0.3 ~ 0.2 in wet at 80°C due to changes in MCTs for each wood species.

From the results, it was concluded that the response of the wood species against the changes of MC and MCT could be recognized as the most, moderate and less affected, as shown in Table 1.

Lida (1989) has been investigated the changes of elastic and strength properties of 24 Japanese wood species by static bending tests in an air-dry condition at 20°C and in water-saturated conditions at 20°C and 100°C. The results showed that there was a difference between the average ratios of young modulus (MOE), breaking stress (MOR), and breaking strain (maximum deflection) of softwoods and hardwoods when moisture content and temperature was increased. He reported that relative MOE and MOR due to change of moisture content for Japanese wood species were 0.52 and 0.62, respectively, and that due to change of temperature were 0.18 and 0.29, respectively. He concluded that the hygrothermal properties of lignin significantly affect the changes of elastic and strength properties of wood that are due to hygrothermal effects. The influence of moisture content changes to MOE and MOR values of the 15 Indonesia wood species were smaller than that of Japanese wood species. On the other hand, the influence of temperature changes was higher.

In this experiment, Agathis, as the only softwood, has most affected by changes of MC and MCT to its MOE and MOR. However, some Indonesian hardwoods were also easily affected by changes of MC to their MOR values, i.e.: Randu, Karet, and Manii woods; and almost all species affected by changes of MCT to their MOR values.

Table 1. Classification of the species based on relative MOE and MOR affected by increasing of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C) (Sudijono *et al*. 2004).

	In wet at 20°C			In wet at 80°C		
	Less	Moderate	Most	Less	Moderate	Most
MOE	Mahoni Acacia Nangka Lamtoro Puspa Bacang	Randu Karet Manii	Agathis		Mahoni Acacia Nangka Lamtoro Puspa Bacang Randu Karet Manii	Agathis
MOR	Mahoni	Acacia Nangka Lamtoro Puspa Bacang	Agathis Randu Karet Manii		Mahoni	Agathis Acacia Nangka Lamtoro Puspa Bacang Randu Karet Manii

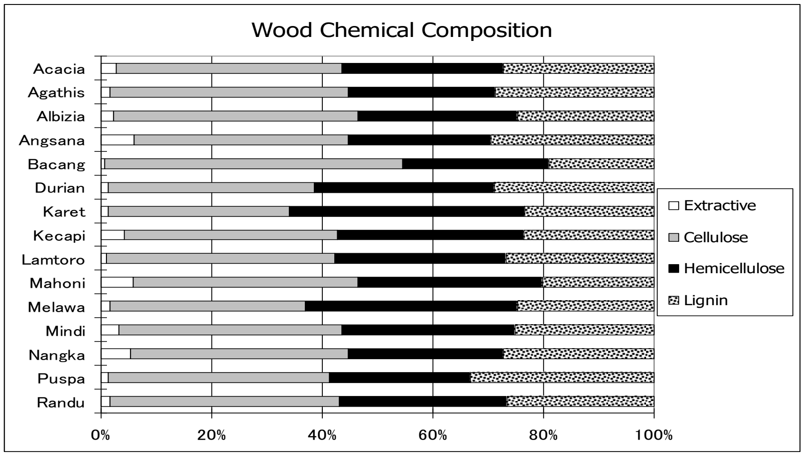

Figure 7. Percentage of α-cellulose, hemicellulose and lignin content in 15 wood species (Yusuf *et al*. 2005)

The results of the chemical composition analysis are shown in Figure 7. The average percentage of α-cellulose, hemicellulose, and lignin content of the 15 wood species were 40.5%, 31.0%, 25.9%, respectively, and the rest were extractive substances. Mahoni, Acacia, Nangka, Lamtoro, Puspa, and Bacang woods contained higher levels of α-cellulose and lower levels of hemicellulose and lignin than the average content. On the other hand, Durian, Karet and Manii woods contained high levels of hemicellulose and lignin and lower levels of α-cellulose than the average content.

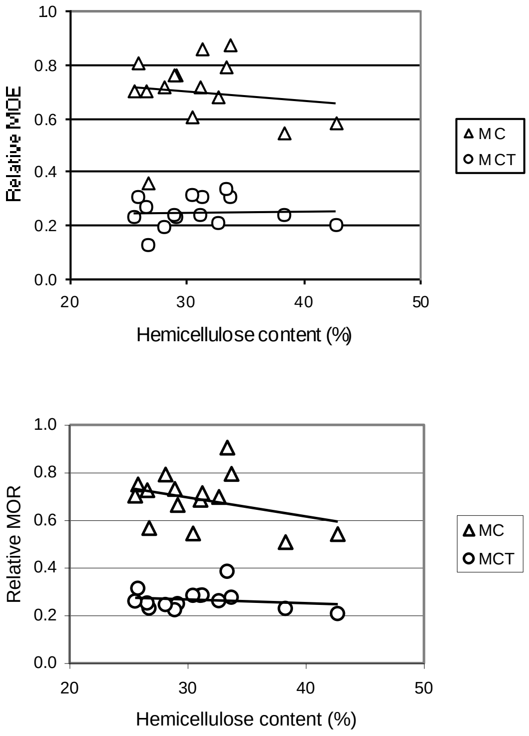

Figure 8. The relationship between the relative MOE and MOR with the percentage of hemicellulose.

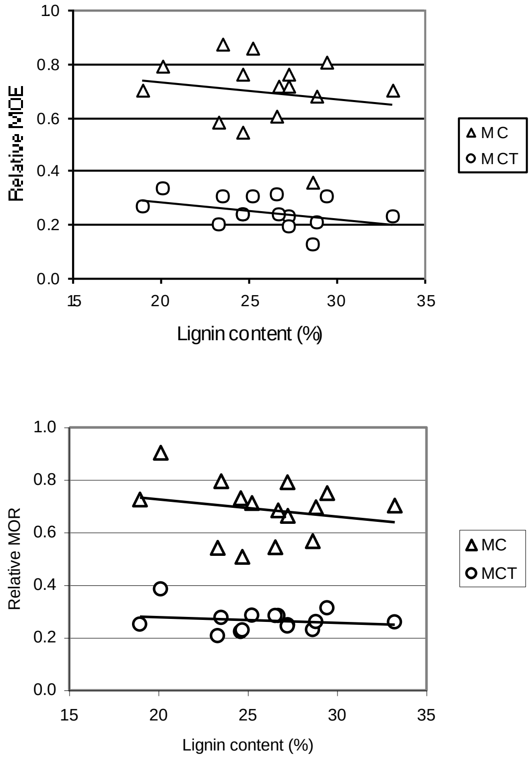

Figure 9. The relationship between the relative MOE and MOR with the percentage of lignin content.

Furthermore, a correlation was made between the relative MOE and MOR and the content of α-cellulose, hemicellulose, and lignin to determine the main factors that influenced the decrease in MOE and MOR due to changes in MC and MCT. The correlation results indicated that the percentage of hemicellulose and lignin in wood species has a role in reducing the static bending properties under softening conditions. The relative MOE and MOR decreased with the increase of hemicellulose and lignin content, particularly due to changes in MC (Figures 8 and 9). However, a decrease in the relative MOE and MOR due to changes in MCT has occurred even though these wood species have low hemicellulose and lignin content. This was indicated by a horizontal line of change in the MOE or MOR value.

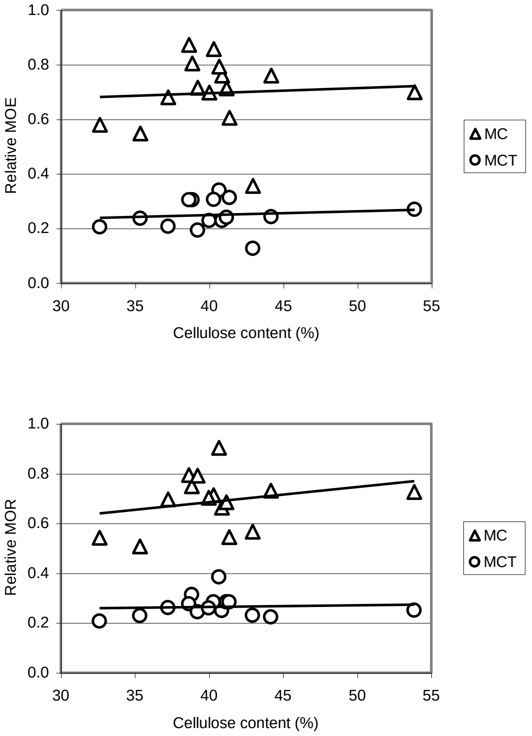

Figure 10. The relationship between the relative MOE and MOR with the percentage of cellulose content.

In contrast, the relative MOE and MOR increased slightly with increasing cellulose content, particularly under changing conditions of MC (Figure 10). This can be understood because cellulose is arranged in microfibrils where the crystal groups cannot be penetrated by water molecules. In addition, the softening temperature of cellulose was still above the treatment temperature in this study (above 80°C). So it can be concluded that the static flexural properties of wood in this softening condition depend on the percentage of cellulose, hemicellulose, and lignin, where wood species that have high cellulose content will be more resistant to changes in MC and MCT.

Conclusions

From the results of the static bending tests, it was recommended that the wood species which were less or moderately affected by changes of moisture content to their MOE or MOR could be used for constructions, furniture, or window frame. We could separate the group into a heavy construction group for less affected wood species by changes of moisture content, such as Mahoni, Acacia, Nangka, Puspa, and Bacang woods, and a light construction group for moderately affected wood species by changes of moisture content, such as Randu, Karet and Manii woods. The wood species, which were easily affected by increasing of moisture content and both moisture content and temperature, might be used for indoor, veneer or raw materials for particleboard.

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