Within Trunk Variation of the Strength Property of Wood from Formosan Alder, Long Glans Oak and Formosan Michelia in Taiwan

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[Summary]

Wood is a biological material and composed of cells of various shapes and sizes. These and the associated changes in the anatomical structure of wood play a major role in the property variations, such as between and within species, growth directions, etc., which have a great effect on the wood utilization. The main purpose of this study is to examine the within trunk variation in the wood strength properties of three important hardwood species native to Taiwan. They are *Alnus formosana* or Formosan Alder (FA), *Cyclobalanopsis longinux* or Long Glans Oak (LGO), and *Michelia formosana* or Formosan Michelia (FM). One tree with straight trunk and no signs of abnormal wood for each species was chosen. The measured DBH values were 60.5, 44.0, and 78.0 cm for FA, LGO, and FM, respectively. Small, clear and streight grained specimen was made from the wood taken from three different heights of each smaple tree trunk. It was found that the MOR of FM wood was stronger than that of LOG. The MOR of FA wood was the weakest among the three. For specific gravity and compression strength, they were shown in decreasing order as LGO, FM, and FA. No consistent variation patterns were found for various strength properties when comparing the results obtained from the different locations, i.e., north, south, east, and west aspect, of the cross section areas at the selected heights of a trunk. The wood strength for FM and LGO showed a decreasing trend with increasing in the trunk height. The reverse was true, however, for FA. From pith toward sapwood, a gradual increase in the strength properties was noted. In general, FA showed a faster rate of growth and larger variation than those of the other two hardwood species tested.

Key words: Wood variation, mechanical property, native wood in Taiwan, hardwood, Formosa Alder, long Glans Oak, Formosan Michelia.

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台灣產赤楊、錐果櫟及烏心石樹幹內木材強度性質變異

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摘　要

木材係一生物材料，由不同大小及形狀細胞組成，這些以及由其隨伴發生之顯微構造差異，爲木材性質變異之一主因，因此，隨生長方向、樹種、以及同樹種之單株內而有變異，同時影響其加工利用。本研究就赤楊、錐果櫟及烏心石三種重要本省固有樹種，進行單株內強度性質變異分析，在試驗中，曾取得赤楊、錐果櫟及烏心石各一株，每株均外觀生長優良、不含不正常木質者。結果發現破壞係數以烏心石優於錐果櫟，而赤楊材最弱，但靜力抗壓強度則以錐果櫟材優於烏心石，三樹種中，錐果櫟材比重最大，烏心石材次之赤楊材最低，綜合各強度性質而言，錐果櫟及烏心石有隨樹高而強度漸減之趨勢，然而赤楊材則隨樹高而漸增，各強度在樹幹之東南西北方位間，並無明顯或一致之變異趨向，由樹心沿年輪至樹皮方向則均顯現增加材料之強度，似拋物線形曲線，惟其間因不同強度性質及樹種而稍有不同，一般而言，赤楊材生長較爲迅速，因而其強度性質之變異性亦大於另二種試驗之樹材。

關鍵詞：木材性質變異性、強度性質、台灣省產木材、闊葉樹材、赤楊、錐果櫟、烏心石。

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Introduction

As a result of its biological origin, wood grows and follows the growth ring and tree height directions to increase its trunk diameter and height. These result in the variations in cell maturity, dimensions and arrangements along the growth directions and, in turn, affect the property of wood and its processing and utilizations (Haygreen and Bowyer, 1987).

Many studies in the past indicated that the physiological factors of growth conditions plays a fundamental role in the life processes and causes a wide range of variation in the mechanical property of wood within a tree and among different trees of a species (Koch, 1985).

Obviously, between tree species, the property varies in a significantly greater degree. This is why a suitable and careful sampling design procedure is essential for performing a reliable test of mechanical property of wood. Other than the aformentioned property variation characteristics of wood, wood material shows distinct property changes at three mutually perpendicular directions, i.e., longitudinal, tangential, and radial directions. This makes the wood a much more complicated material to be studied as compared to the other isotropic non-biological materials (Koch, 1985; Boding and Jayne, 1982).

This study project, under the main project entitled "Studies on the fundamental properties of the economical tree species in Taiwan", is aimed at studying the variation in the mechanical properties within a single tree trunk of wood from fifteen economical tree species native to Taiwan. This project was undertaken for a period of five consecutive years. The properties studied included static bending, compression parallel to the grain and shear strength of wood.

The fifteen tree species included in the project are Taiwan hinoki, Taiwan red cypress, Chinese hemlock, Taiwan spruce, Taiwan fir, Taiwania, Japanese fir, China fir, Formosan China fir, Formosan michelia, Long glans oak, Formosan alder, Caudate leaved chinkapin, Taiwan zelkova, and Formosan ash. Formosan michelia, Long glans oak, and Formosan alder were used in this study.

Test Material and Methods

The wood of Formosan Michelia (FM) (*Michelia formosana*), Long Glans Oak (LGO) (*Cyclobalanopsis longinus*) and Formosan Alder (FA) (*Alnus formosana*) was used for the preparation of the test material. One sample tree for each wood species was selected. Care was taken to select trees that had a straight trunk and no signs of abnormal wood. In all, three sample trees were taken. Table 1 describes the sample trees with regard to the date of felling, tree height, height to the lowest branch, trunk length harvested, diameter at breast height, growth elevation and land slope. Four bolts, about one meter in length, were cut from each sample tree. The north, south, east, and west sides of the sample bolt were identified and marked for later sampling purpose. Table 2 shows the height above ground that the sample bolts were cut. In total, from the three trees sampled (three wood species), twelve sample bolts were taken.

Table 1. Sample tree description

Wood species	*Michelia formosana*	*Cyclobalanopsis longinux*	*Alnus formosana*
Cutting date	78/12/22	78/12/21	79/1/10
Tree Ht.	32.0 m	26.9 m	24.3 m
Harvested length	25.5 m	21.4 m	19.9 m
Ht. to branch	19.2 m	3.8 m	14.2 m
DBH	78.0 cm	44.0 cm	60.5 cm
Tree growth elevation	1,500 m	1,500 m	1,800 m
Ground slope	30 Deg.	25 Deg.	40 Deg.
Location	Tahu*station	Tahu*station	Taanchi*station

*Hsinchu forest district, Taiwan forest bureau.

Table 2. Height of trunk for each tree sampled

Sampling height expected	Actual height sampled		
	Michelia formosana	*Cyclobalanopsis longinux*	*Alnus formosana*
Butt (Ground Ht.)	1.8- 2.8 m	1.6- 2.6 m	1.4- 2.6 m
1/4 Ht.	6.6- 7.6 m	6.0- 7.0 m	7.0- 8.0 m
2/4 Ht.	11.0-12.0 m	11.5-12.5 m	11.5-12.5 m
3/4 Ht.	16.0-17.0 m	16.0-17.0 m	15.0-16.0 m

The sample bolt was sawed using a band saw. Three inches thick quarter-sawn boards according to north, south, east, and west direction through pith were obtained. All the boards were then stacked and air-dried before further machining. Air-dried boards from sample bolts were sawn carefully to yield 2 × 2 cm straight-grained sticks with tangential and radial surfaces. Care was taken again to mark these sampled sticks so as to identify their original positions on the cross section of a sample bolt.

The standard-sized, small, clear, straight-grained static bending, compression parallel to the grain and shear strength test specimens were prepared according to CNS 453–455 and 460. Standard procedures, in accordance with these CNS Standards were followed and the tests were done on a 15 ton Instron testing machine. Bending samples were tested tangentially to reduce growth ring effect. Both density and moisture content determinations were made. Density was measured, based on oven-dry-weight and air-dried volume of the sample.

All the test results, including modulus of rupture (MOR) and modulus of elasticity (MOE), compression strength parallel to the grain and shear were adjusted to sixteen percent moisutre content based on the method described by Wood Handbook (USDA, Forest Service, 1984).

Results and Discussion

Changes in wood properties as related to the height positions and locations on the cross section of a trunk were indicated by the results of the strength property tests on Formosan Alder (FA), Long Glans Oak (LGO) and Formosan Michelia (FM) wood. Table 3 shows the summary of the analysis of variance (ANOVA), which pointed out the significant differences in tree height and cross-sectional location. Among the various strength tests, i.e., static bending, shear and compression parallel to the grain, static bending property gave a greater variation than the other two. The results from the test of wood specific gravity also indicated that the difference as a result of trunk height was more significant than cross-sectional location. The significant difference in the test results of the compression strength was found for FA wood, however.

Table 3. Summary of the analysis of variance (ANOVA) for the wood properties of Formosan Alder (FA), Long Glans Oak (LGO), and Formosan Michelia (FM)

Source of variation	MOR kgf/cm^2	MOE kgf/cm^2	Shear kgf/cm^2	Comp. kgf/cm^2	Specific gravity	Wood species
HT	4.33*	1.80	6.77*	11.42*	13.46*	FA
DIR	0.71	4.24*	1.72	3.82*	1.08	
HT × DIR	1.79	3.80*	2.16	5.41*	4.59*	
HT	4.15*	8.37*	2.66	3.67	4.09*	LGO
DIR	1.80	7.45*	1.69	1.81	2.88	
HT × DIR	1.90	4.85*	1.57	2.58	2.88	
HT	49.54*	13.55*	1.30	1.76	31.85*	FM
DIR	2.20	3.42	3.75	3.74	1.29	
HT × DIR	11.24*	7.82*	3.48	2.98	8.66*	

DIR:Direction; Ht.:Height; MOR:Modulus of Rupture; MOE:Modulus of Elasticity; Comp.:Compression.
*Significant at the 95 percent level of confidence.

Table 4. describes the results of the modulus of rupture mean, modulus of elasticity mean, shear strength mean, wood specific gravity mean, and compression strength mean according to stem height and cross-sectiional location of sampling for FM wood. The plot of mean modulus of rupture versus trunk height and cross-sectional location (represented by north (N), south (S), west (W) and east (E) directions) is shown in Fig. 1.

Table 4. and Fig. 1 pointed out the decreasing trend in wood static bending strength with increasing in the trunk height. Both shear and compression strengthes were not significantly different regarding height as shown in Table 4. Please note that in Fig. 1, only the mean values of the south and west directions of top bolt (i.e., 3/4 stem height of sampling) were shown. An effort was made to prepare test specimens from the north and east sides of the top sample bolt. The attempt was not accomplished because of the occurrences of large branches and Knots, which hindered the test specimen preparations.

Table 4 and Fig. 1 also show that the west direction of the tree trunk is stronger than the other three directions. Although the higher wood specific gravity value of the west side was not found to be significant, the mean values of MOR, MOE and shear were

Table 4. Significance test of wood property means by stem height and direction of sample for wood of Formosan Michelia (FM)

		MOR. kgf/cm²	MOE. kgf/cm²	Shear. kgf/cm²	Comp. kgf/cm²	Specific gravity
Trunk height	Butt	1510 A	154869 A	186 A	516 A	0.494 C
	1/4 Ht	1307 B	139339 B	193 A	505 A	0.505 B
	2/4 Ht	1342 B	144840 B	190 A	510 A	0.518 A
Cross section direction	North	1373 B	142433 B	189 B	513 A	0.504 A
	South	1383 B	146060 B	186 B	510 AB	0.502 A
	West	1452 A	154597 A	200 A	522 A	0.509 A
	East	1401 AB	147813 AB	183 B	497 B	0.502 A

The same alphabetes follow the means of property tests indicate that the differences are not significant at the 95 percent level of confidence by Duncan's new multiple range test. The property codes are the same as those noted in Table 3.

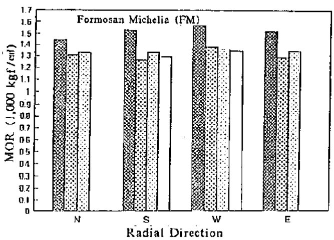

Fig. 1. Plot of modulus of rupture means versus trunk height and direction of sample for Formosan Michelia wood.
Trunk Height: Butt, 1/4Ht. 2/4Ht. 3/4Ht.
N: North; S: South; W: West; E: East.

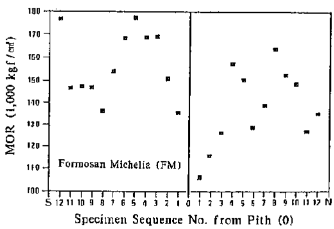

Fig. 2. Plot of modulus of elasticity versus distance from pith of sample for Formosan Michelia wood. S: South Aspect; N: North Aspect.

all significantly higher at west side than at the other three sides. Fig. 2 depicts one plot of modulus of elasticity mean against distance from pith of FM wood. It suggested a gradual increase in the wood strength following the first test sample from pith for both north and south directions. The property of strength tends to reach a maximum, drop and then rise again.

The significance tests of the means of modulus of rupture, modulus of elasticity, shear, specific gravity, and compression paralled to the grain for LGO wood were shown in Table 5 by stem height and cross-sectional position of sampling.

It indicates the significant effects by trunk height and horizontal position of wood. A strong influence by trunk height of sampling is illustrated by Fig. 3, which depicts the change in modulus of rupture with trunk height at north, south, west and east cross-sectional directions. The plots shown in Fig. 3 explicitly display a decreasing trend of wood strength with increasing in the height of tree trunk. This lowering trend was also found for FM wood. In Table 5, these variation characteristics were shown to be significant for all the test means. The results obtained from wood specific gravity, compression parallel to the grain and shear tests indicated the drops in mean values at the butt of trunk, however. Table 5 also points out the significant variations in static bending strength property and wood specific gravity at the different directions of a cross section of a trunk for LGO tree.

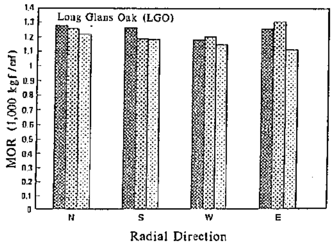

Fig. 3. Plot of modulus of rupture means versus trunk height and direction of sample for *Long Glans Oak* wood.
Trunk Height: Butt, 1/4Ht. 2/4Ht.
N: North; S: South; W: West; E: East.

Table 5. Significance test of wood property means by stem height and direction of sample for wood of *Long Glans Oak* (LGO)

		MOR kgf/cm²	MOE kgf/cm²	Shear kgf/cm²	Comp. kgf/cm²	Specific gravity
Trunk height	Butt	1248 A	150107 A	276 B	651 B	0.786 B
	1/4Ht.	1240 A	146112 A	298 A	674 A	0.809 A
	2/4Ht.	1169 B	132913 B	289 AB	651 B	0.778 B
Cross section direction	North	1258 A	155731 A	291 A	645 A	0.803 A
	South	1221 AB	139966 BC	277 A	655 A	0.770 B
	West	1179 B	134121 C	280 A	667 A	0.800 A
	East	1229 AB	145187 B	300 A	668 A	0.790 AB

The same alphabetes follow the means of wood property tests indicate that the differences are not significant at the 95 percent level of confidence by Duncan's new multiple range test. The property codes are the same as those noted in Table 3.

The wood property variation within a trunk of FA wood was shown by the static bending, compression parallel to the grain, shear and specific gravity property tests. A summary of the test means of FA wood samples and significance tests of the means according the the trunk height and direction at cross section area of sampling was presented in Table 6. In comparision with the mean results at the different trunk height of sampling, the increase in the specific gravity of wood and its strength properties with increasing in the height of trunk is readily noted. This is further indicated in Fig. 4, which gives one plot of the means of modulus of rupture against the trunk height of sampling by the different sides of a trunk. The increase in all the properties tested were statistically significant except the mean values of modulus of elasticity as shown in Table 6. The significant variations in FA wood were also found for the mean values of modulus of elasticity, shear and compression par allel to the grain strength properties by locations of sample at different cross section directions of a trunk.

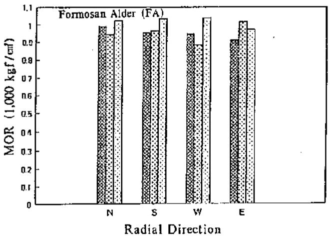

Fig. 4. Plot of modulus of rupture means versus trunk height and direction of sample for *Formosan Alder* wood.
Trunk Height: Butt, 1/4Ht. 2/4Ht.
N: North; S: South; W: West; E: East.

As shown in Table 4, 5 and 6, high specific gravity values were obtained from the tests for LGO wood. The average values ranged from 0.770 to 0.809, which were much higher than FM and FA wood, ranging from 0.494 to 0.518 and 0.443 to 0.472, respectively. Both compression and shear strength pro-perties showed a similar trend found in the mean values of wood specific gravity, i.e., in decreasing order as LGO, FM, and FA. In the case of static bending, however, the test results indicate a stronger wood of FM than LGO for both MOR and MOE. Among cross-sectional directions of sample, there was no specific pattern of variation among test means of various strength properties and specific gravity, by wood species, albeit the significantly different results were found. The sample bolts obtained from 3/4 height position for both LGO and FA tree trunk contained large knots causing severe grain deviations and, therefore, were not tested in this experiment.

Table 6. Significance test of wood property means by stem height and direction of sample for wood of Formosan Alder (FA)

		MOR kgf/cm²	MOE kgf/cm²	Shear kgf/cm²	Comp. kgf/cm²	Specific gravity
Trunk height	Butt	954 B	117606 A	168 B	343 B	0.443 B
	1/4 Ht.	941 B	112871 A	179 A	353 B	0.447 B
	2/4 Ht.	1019 A	120157 A	182 A	370 A	0.472 A
Cross section direction	North	986 A	125314 A	174 AB	356 A	0.448 A
	South	978 A	113223 B	181 A	357 A	0.460 A
	West	946 A	115612 B	170 B	341 B	0.451 A
	East	960 A	111778 B	176 AB	363 A	0.449 A

The same alphabetes follow the means of wood property tests indicate that the differences are not significant at the 95 percent level of confidence by Duncan's new multiple range test. The property codes are the same as those noted in Table 3.

Changes in the properties of LGO and FA wood from pith toward bark were investigated by plotting test results versus distance from pith of sample. Fig. 5 represents one of the plots concerning modulus of rupture property at south and north directions of butt bolts. A slight drop in core zone and then gradual increase toward sapwood for both wood species was noted. In addition, there appeared a larger variation in wood for FA than for LGO, which may partially be attributed to the faster growth rate of FA wood. Large variations in wood property were also found in testing fast growing leucaena hardwood (Tang, 1986) and hemlock softwood (Tang, 1990). FA wood showed a second low value for MOE from pith toward sapwood. This was also the case for FM wood as shown in Fig. 2.

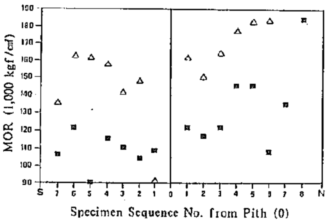

Fig. 5. Plot of modulus of elasticity versus distance from pith of sample for the wood of Long Glans Oak and Formosan Alder.
△: Long Glans Oak; ■: Formosan Alder
S: South Aspect; N: North A pect.

Conclusion

The variation in the wood strength properties was investigated using the wood from *Alnus formosana* (Formosan Alder (FA)), *Cyclobalanopsis longinux* (Long Glans Oak (LGO)), and *Michelia formosana* (Formosan Michelia (FM)). The study results were analyzed according to the height position and radial directions (north, south, east, and west) within a tree trunk. The following conclusions can be drawn:

1. Both the static bending and compression test results gave a better indication as to how they vary within a trunk, whereas the results obtained from the shear test were, in some cases, erratic.
2. The MOR of FM wood was higher than that of LGO. The MOR of FA was the lowest. For specific gravity and compression strength, they were shown in decreasing order as LGO, FM, and FA.
3. The wood strength for FM and LGO showed a decreasing trend with increasing in trunk height. The reverse was true, however, for FA wood.
4. In the radial direction from pith toward sapwood, a gradual increase in the strength was shown for all three wood species.
5. No consistent variation pattern was found among different aspects i.e., north, south, east, and west, of a trunk at the selected heights of a tree.
6. FA showed a faster growth rate and larger variation in wood property than those of the other two hardwood species studied.

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