STRENGTH ASSESSMENT OF STRUCTURAL SIZE MALAYSIAN TIMBERS

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ABSTRACT

Existing strength data of Malaysian timbers are based on mechanical tests of small clear specimen. The formal mechanical properties assessment of timber in structural sizes has not been carried out for most tropical species, including Malaysian timbers. The present study is a groundwork testing on some selected commercial timbers to develop correlation factors between structural size and small clear specimens of timber in bending. A total of 120 planks of mixed species of Malaysian hardwoods were cut into standard sizes for structural size bending test as mentioned in EN 408:2003 and small clear specimen of 50 mm by 50 mm (2 inches by 2 inches) size according to ASTM D143 - 52. The ultimate results of MOR and MOE between the two testing methods were evaluated. Weak MOR correlation was observed between small clear and structural specimens. MOE relationship was shown to be consistent even for unconditioned and ungraded specimens. However, the risk of inaccurate deflection measurement is much higher for MOE in structural test. The developed correlation factors are then applicable for the data conversion of timbers in similar strength group where only small clear data exist. A robust statistical technique was introduced to group the Malaysian timbers into similar strength classes. The grouping is intended to simplify the conversion work of the existing strength data to equivalent structural size values.

ABSTRAK

Data kekuatan kayu-kayan Malaysia yang direkodkan adalah berdasarkan ujian mekanikal ke atas spesimen bersaiz kecil. Penentuan sifat-sifat mekanikal kayu bersaiz struktur masih belum dilaksanakan secara formal untuk kebanyakan spesis tropika termasuklah kayu-kayan Malaysia. Kajian ini merupakan ujian awalan ke atas beberapa kayu komersial terpilih, bertujuan untuk membangunkan faktor kolerasi di antara spesimen bersaiz struktur dan kecil menerusi ujian lenturan. Sebanyak 120 papan kayu yang terdiri dari pelbagai spesis kayu keras Malaysia telah dipotong kepada saiz piawai untuk ujian struktur seperti yang dinyatakan di dalam EN 408:2003 dan spesimen saiz kecil 50 mm kali 50 mm (2 inci kali 2 inci) berdasarkan ASTM D143 – 52. Nilai MOR dan MOE di antara kedua-dua kaedah ujian tersebut ditentukan. Hubungan MOR yang lemah diperhatikan di antara spesimen kecil dan struktur. Hubungan MOE menunjukkan keseragaman walaupun spesimen tidak dikondisi dan digred. Namun begitu, risiko ralat semasa pengukuran nilai lenturan di dalam ujian struktur adalah tinggi. Faktor-faktor kolerasi yang telah dibangunkan akan digunakan untuk manipulasi data kekuatan kayu yang sedia ada berdasarkan kumpulan kekuatan yang sama. Satu kaedah statistik telah diperkenalkan untuk mengklasifikasikan kayu-kayan Malaysia berdasarkan kumpulan kekuatan yang sama. Klasifikasi tersebut bertujuan untuk memudahkan tatacara kolerasi data yang sedia ada kepada nilai kekuatan saiz struktur yang sepadan.

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LIST OF ABBREVIATIONS

Abbreviation	Description
CE	"Conformité Européene" (European Conformity)
CO_2	carbon dioxide
CPD	Construction Products Directive
EEA	European Economic Area
EU	European Union
FRIM	Forest Research Institute Malaysia
FPC	factory production control
GHG	greenhouse gas
ITT	initial type test
LRM	Light Red Meranti
MC	moisture content
MOE	modulus of elasticity
MOR	modulus of rupture
MTC	Malaysian Timber Council
MTIB	Malaysian Timber Industry Board
MWIA	Malaysian Wood Industries Association
S.G.	strength group
SD	standard deviation
SG	specific gravity

CHAPTER 1

INTRODUCTION

1.1 GENERAL BACKGROUND

Timbers harvested in Malaysia were being exported for load bearing beams, columns, ties and other structural applications. According to New York Times, Europe is Malaysia's second-largest timber export market after Japan, with a total of RM2.67 billion in sales of timber and timber products in 2009. Tropical hardwoods are greatly demanded in most importer countries mainly for their appearance and strength properties, widely being used as building materials in the construction industries.

Standard tests to determine strength properties of various species of Malaysian timbers were conducted on small clear timber specimens and the results obtained cannot be used directly by engineers or architects in timber design. The ultimate stresses obtained from tests have to be reduced to account for various strength reducing factors before suitable data for design purposes are obtained. Hitherto in Malaysian timber engineering practice, the ultimate stresses obtained from tests were reduced by applying arbitrary factors to obtain what is called working stresses. These arbitrary reduction factors account for variability of timber, duration and conditions of loading, and factor of safety. Undoubtedly these factors are necessarily conservative and consequently result in poor utilization of timber for structural purposes (Engku, 1971).

As a biological material, timber shows a large variability on its mechanical properties that turns into an extremely difficult strength assessment. Strength and surface hardness of timber are closely related to density, but strength is markedly reduced by grain deviation, knots and brittle heart. Pieces containing brittle heart are usually light in weight, low in strength and liable to sudden fracture. Clear strength of timber is derived from the tests using small, clear, defect free samples. While the small clear wood specimens testing method may have been convenient from a wood scientist point of view, it cannot provide a reliable basis for structural purposes. Engineers and designers need reliable and accurate information pertaining to the properties and performances of the timber. It is well known that using the results from full size structural timber test was considered to be more reliable to allocate the design stress as to eliminate the risk of stress ratio assumptions. In addition, the values will reflect more on the actual strength of timber in use (Madsen, 1992).

Throughout the world, the practice of structural size testing for mechanical properties determination of timber had been long-established. The formal stress grading system in the United States got its start since 1902 with tests of both small and structural size specimens (Galligan and Green, 1984). The arrangement for structural size timber test varies in different parts of the world. In Australia and North America, modulus of elasticity is measured from deflection of middle point between supports, which is often referred to as a global measurement, while in Europe the measurement is made over a gauge length in between two loading point of the beam, which usually referred to as local measurement (Bostrom, 1999). Although there are some differences in the testing setups, but generally the testing are conducted on specimens in structural sizes.

1.2 PROBLEM STATEMENT

Malaysia is endowed with more than 3000 timber species which are suitable for a variety of uses, with over hundred of commercially known species (Wong, 1982). It is impossible to characterize all tropical hardwood species based on large specimen’s properties as far as European softwoods. This approach, which optimizes the relation between species singularities and strength, cannot be used for tropical hardwoods due to the huge number of tropical species. The variety of tropical timber species as compared with temperate species would imply the need for extensive and expensive testing work. In addition, the new requirement would limit the introduction of lesser known species in the market (Anon., 2006).

Several discussions in the national level had been held regarding the possible setback and risk of the structural size timber testing if the assessment is to be executed. The laboratories appointed to conduct the assessment should be concern on the capacity of staff and facility available. Governmental organizations such as Malaysian Timber Industrial Board (MTIB) and Malaysian Timber Council (MTC) should be aware of the high expenses needed to procure the samples required to execute the testing. Millions of Ringgit has to be invested to fund the testing of over hundred of marketable timber species in large sizes. Eventually the amount of tested specimens plus remnants from the samples which are not reusable for structural application is just like creating more damages to the timber businesses rather than serving them. Not to overlook the risk of unavailable timber species owing to the statistics of what is still available in the Malaysian forests. Above and beyond, the duration of time needed to accomplish the assessment would be unpredictable.

There are only two means for the determination of mechanical properties of timber in structural sizes; one is to conduct the destructive structural size test, or, the other way is to manipulate the existing small clear data so that it is equivalent to the properties obtained from structural size test. Thus, this study aims to establish the relationship between small clear and structural size timber specimens that leads to the more accurate structural strength and stiffness values.

1.3 IMPORTANCE OF STUDY

The natural variability of wood, in contrast to the homogeneous man-made building materials of steel, concrete and artificial composites such as fibre glass, has long been a challenge to the timber researchers. To put a better market value for Malaysian timbers, an attempt has been made to better understand the relationship between small clear timber specimen and structural size properties that leads to the more precise mechanical strength values. So far, in Malaysia, there were very few researches done on the strength relationship between structural size timber and two inches small clear timber specimen in bending, and almost none properly documented. Specifically, the objective of this investigation is to propose conversion factor for converting the existing timber strength data which was based on small clear timber specimen tests to a new data set of structural size strength values.

1.4 OBJECTIVES

i. To perform structural size bending test based on EN408 testing standard for selected commercial species of Malaysian timber. The testing procedure is adopted from a method currently used in Europe, EN 408 - Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties.

ii. To come out with a robust and straightforward procedure for grouping Malaysian timbers into similar strength classifications. The procedure is intended to enhance the existing timber strength groupings and assists the implementation of the conversion factors.

iii. To derive conversion factors for bending strength and modulus of elasticity between structural size and small clear specimen timber.

1.5 SCOPE OF WORK

i. Static bending test will be conducted on two group of samples based on small ASTM D143-52 and EN408:2003 testing methods. Modulus of rupture (MOR), modulus of elasticity (MOE) and density will be determined.

ii. Student's t-test analysis will be conducted on mechanical properties of selected timber species for the assessment of similar strength grouping.

iii. Conversion factors for MOR, MOE and density between structural size and small clear specimen timber will be developed based on results of sample group 2 (Light Red Meranti).

1.6 THESIS LAYOUT

The layout of this thesis is presented in Figure 1.1.

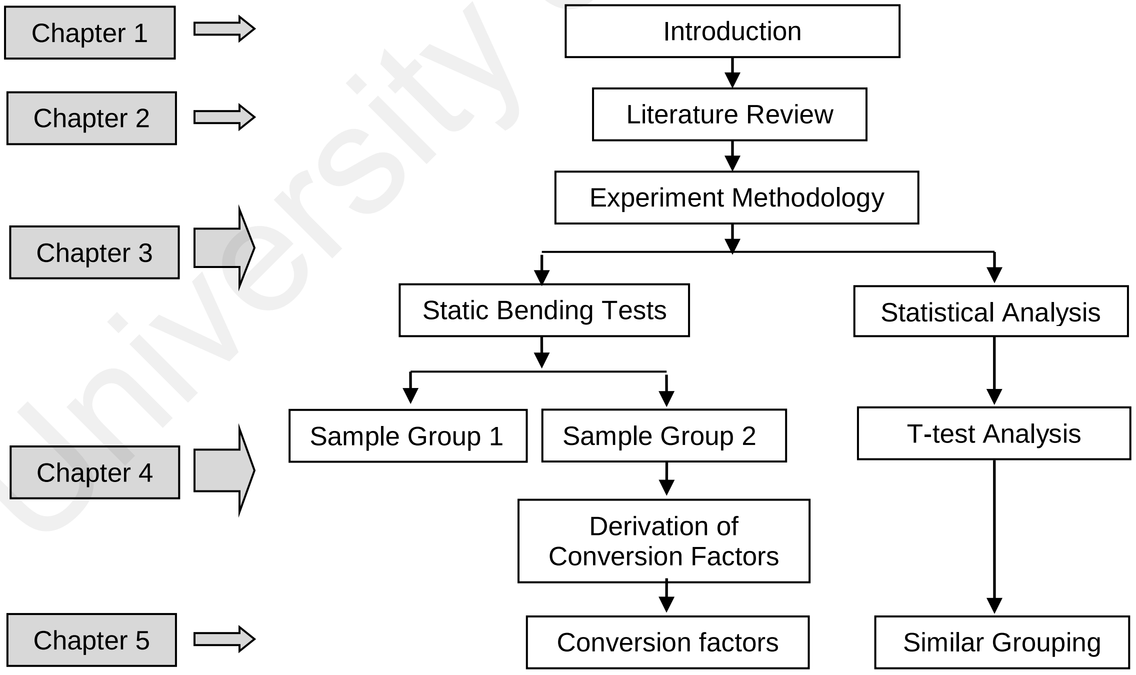


Figure 1.1. Thesis layout.

CHAPTER 2

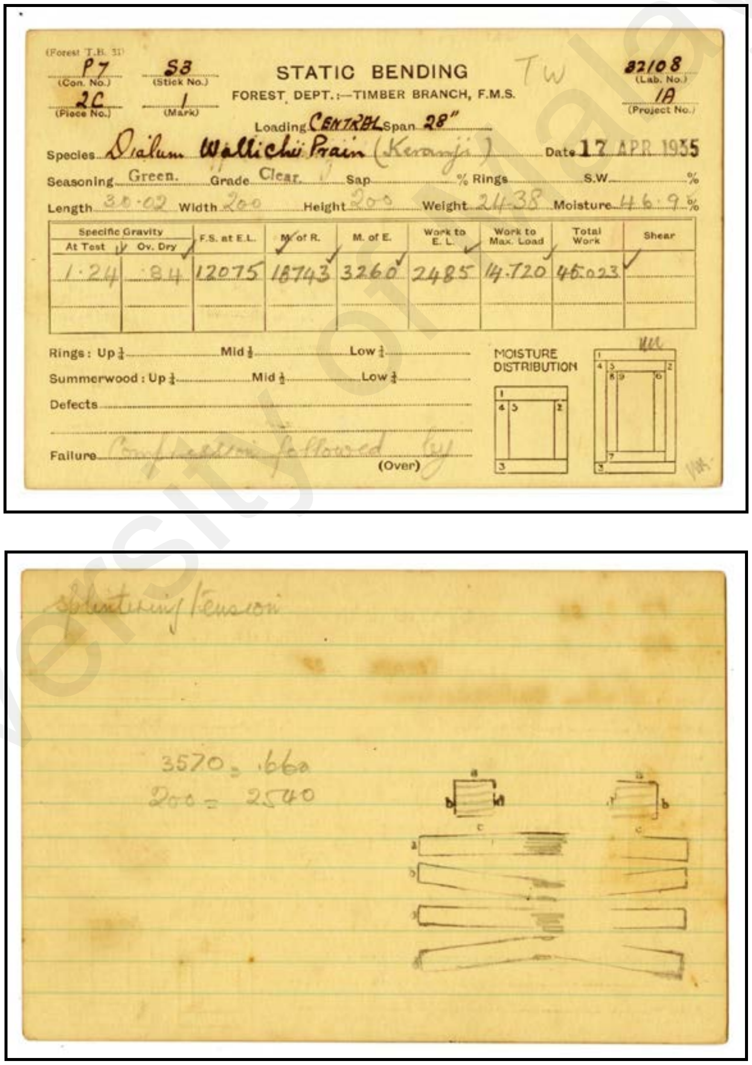
LITERATURE REVIEW

2.1 MECHANICAL PROPERTIES OF MALAYSIAN TIMBERS

Anecdotal evidences indicate that the assessment of the mechanical properties of Malaysian timbers started circa 1920's, most probably by the Englishmen due to the time of British colonization. Most of the original data still exists in a card file system in Timber Engineering Laboratory of Forest Research Institute Malaysia (FRIM). However, fractions of the data were destroyed during the wartime of Japanese occupation and some were attacked by termites. The neat and systematic handwriting on the cards dated back as far as 1929 are still clearly visible. Common sense dictates that the effort must have been done under the colonial administration, considering the level of education of the locals during that time.

Figure 2.1(a) and (b) show a card file dated 17 April 1935, an antique timber testing records that still possess the proper original look salvaged by Timber Engineering Laboratory. The card was neatly hand-written, containing static bending test result of a Keranji's specimen of the genus *Dialium*. The test was conducted on a 50 mm x 50 mm x 760 mm (2 inches x 2 inches x 30 inches) specimen in green condition. It holds the record of specimen's weight, MC, SG, MOR, MOE and work. A failure mode was described as "*Compression followed by splintering tension*" with a few sketches on the back of the card.

In general, the Malaysian timbers had undergone two different segments of mechanical properties development. It is supposed that the strength assessment began in the twenties and from that day the collection of the strength data started. Various reports and publications were disseminated and from time to time the compilation was updated with data of new properties and species. The second segment was when the collections were categorized into groups, initially A, B, C and D grouping and subsequently designated into Strength Group (S.G.) 1 to 7. Although these evolutions may not directly influenced the aim of this study – that is to provide the basis for conversion factor development, a brief review of this matter might provide a good guidance for the similar strength grouping assessment.


(Forest T.B. 31)

P7 (Con. No.) 53 (Stick No.)

2C (Piece No.) 1 (Mark)

STATIC BENDING TW

FOREST DEPT.:—TIMBER BRANCH, F.M.S.

82108 (Lab. No.)

1A (Project No.)

Loading CENTRAL Span 28"

Species Dialum Wallichii Prain (Keranji) Date 17 APR 1935

Seasoning Green. Grade Clear. Sap % Rings S.W. %

Length 30·02 Width 200 Height 200 Weight 24·38 Moisture 46·9 %

Specific Gravity		F.S. at E.L.	M. of R.	M. of E.	Work to E. L.	Work to Max. Load	Total Work	Shear
At Test	Ov. Dry							
1·24	·84	12075	18743	3260	2485	14·720	45·023	

Rings: Up ⅓ Mid ⅓ Low ⅓

Summerwood: Up ⅓ Mid ⅓ Low ⅓

Defects

Failure Compression followed by

(Over)

MOISTURE DISTRIBUTION

splintering tension

3570 = ·660

200 = 2540

Figure 2.1(a) and (b). A card file dated 17 April 1935 containing static bending test result of a Keranji specimen.

2.2 THE EARLY TESTING

The earliest report on mechanical properties of Malaysian timbers was written by A.V. Thomas (1940). It was documented in the Malayan Forester, number 4 of volume 9, which gave only the results of some mechanical tests on green timber specimens. This report was subsequently published as Trade Leaflet No.5 entitled Malayan Timbers Tested in a Green Condition. Since then much more data on strength and physical properties had been collected. Following a report by Lee Yew Hon and Chu Yue Pun (1965) an effort was made to rationalise the working stresses for Malaysian timbers based on the available tests results. The derivation of working stresses was made more urgent because of the need to incorporate them in the Malaysian Standard Code of Practice for Structural Use of Timber (Lee et al., 1993).

The compilation of tests results for the ultimate stresses of Malaysian timbers is represented in the Timber Trade Leaflet No.34 (Lee et al., 1993) which supersedes Trade Leaflet No.5. Not only the mean values reported, but also the number of tests and the standard deviations of the test results were recorded. However, the data presented are by no means complete. Further tests are required on some species where some strength properties had not been estimated or had been inadequately estimated. It is well to realise that the values assigned to each property were only estimated, partly because they were based on a small volume of test material compared to the amount of timber available and partly because there was variation in wood properties even in a tree (Lee et al., 1993).

The mechanical tests were conducted based on standard mechanical tests on small clear specimens of timber. Tree log of girth between 190 cm and 270 cm were cut into 5.7 cm square sticks, and planed to exactly 50.8 mm square (2 inches square). Half the sticks were tested in green condition and the rest in a fully air-dried condition, within the range of

13.4 % to 19.7 % moisture content. The method of testing had been described in some detail in Malayan Forest Record No.13 (Anon., 1959). The procedures were similar to BS 373:1957 for 50 mm (2 inches) specimens and ASTM D143 – 52 (Engku, 1971). Small clear specimen is defined as specimen with no visible defect over the specimen's length. For tropical timber this is difficult to distinguish. In practice, even the grain angle deviation is not easy to be determined (Geert and van de Kuilen, 2010). In fact, clear and straight-grained specimens may be expected to exhibit slight variability in mechanical properties along the length (Gromala, 1985). Thus it is practical to assume that for Malaysian timbers, the tested specimens were the corresponding small clear specimens. Therefore the mechanical properties of timber listed in Timber Trade Leaflet No.34 - The Strength Properties of Some Malaysian Timbers, were obtained through small clear specimen test of 50 mm (2 inches) standard (Lee et al., 1993).

Series of discussion by Technical Committee on Strength of Timber in FRIM resolved some deficiencies regarding the issue of mechanical properties listed in Timber Trade Leaflet No.34:

i. Results for some tests for some species are not available, most probably because they have never been tested. For example: Static Bending and Cleavage tests for Perah (*Elateriospermum tapos*), Petaling (*Ochanostachys amentace*), Pauh Kijang (*Irvingia malayana*) etc.
ii. Some air-dried specimen results are not given. Lee and Chu (1965) explained that the air dried specimens had been lost during the World War II period.
iii. In the "Consignment Test", five trees are required to provide the test material for each species. However, most of the data enclosed obtained from three trees in series of "Pilot Test" and some were obtained from only one tree in series of "Extra Test".

iv. Basic and grade stresses were derived from the ultimate stresses in Timber Trade Leaflet No.34 through the formula:

$$[(X - 2.33\,\sigma)/\,factor\ of\ \ safety] \tag{2.1}$$

where X is the mean ultimate stress and σ is the standard deviation. A low σ indicated that the basic stress tends to be high whereas high σ indicated that the basic stress is dropped to a low value. The quantity of specimen for some tests in Timber Trade Leaflet No.34 were less than 10, consequently the value of σ tends to be very high and resulted in poor depiction of the timber true strength.

Standard tests to determine mechanical properties of Malaysian timbers were conducted on small clear timber specimens and the results obtained cannot be used directly by engineers or architects in timber design. The ultimate stresses obtained from tests had to be reduced to account for various strength reducing factors before suitable data for design purposes were obtained. Hitherto in Malaysian timber engineering practice, the ultimate stresses obtained from tests were reduced by applying various factors to obtain what is called working stresses. These arbitrary reduction factors accounted for variability of timber, duration and conditions of loading, and factor of safety. Undoubtedly, these factors were necessarily conservative and consequently resulted in poor utilization of timber for structural purposes (Engku, 1971).

2.3 THE SPECIES GROUPING

Under practical consideration, classification of the Malaysian timbers in different groups based on the strength was essential in view of difficulty faced in differentiating some of the species and the availability of a particular species (Hilmi et al., 1996). To the timber supplier, stocking of so many species may cause substantial difficulty. Therefore by grouping the species, the construction designer need only specify the strength group without worrying about the species and the availability. This was beneficial not only to the designer but to the supplier as well. Under the older method of grouping Malaysian timbers into strength groups, only the compressive strength was considered (Burgess, 1956). However, in deciding the position of the timber in the group, bending strength had also been considered. The grouping is shown in Table 2.1. This method divided timbers into four strength group, A, B, C and D.

Group A is considered as extremely strong and contains timbers with compressive strength of above 8000 lbf/in^2 (55.2 Mpa).

Group B is very strong and contains timbers with compressive strength of between 6000 – 8000 lbf/in^2 (41.4 – 55.2 Mpa).

Group C is strong and the timbers herein are those with compressive strength of 4000 – 6000 lbf/in^2 (27.6 – 41.4 Mpa).

Group D is the weakest and the timbers classed here are those with compressive strength of less than 4000 lbf/in^2 (27.6 Mpa).

Table 2.1. Strength groups of Malaysian timbers by Burgess (1956).

Group A	**Group B**	**Group C**	**Group D**
Bitis	Kempas	Teak*	Durian
Keranji	Perupok	Simpoh	Douglas Fir*
Cengal	Keledang	Kungkur	Sesendok
Iron Bark*	Merbau	Kasai	Jelutong
Balau	Kulim	Sepetir	Scots Pine*
Giam	Resak	Machang	Medang
Red Balau	Kelat	Mempisang	Pulai
	Mengkulang	Ramin	Terentang
	Rengas	Meranti, Bakau	Geronggang
	Keruing	Melunak	
	Kapur	Jarrah*	
	Tualang	Merawan	
	Tembusu	Penarahan	
	Dedaru	White Meranti	
		Nyatoh	
		Dark Red Meranti	
		Bintangor	
		Punah	
		Mersawa	
		Terap	
		Kedondong	
		Yellow Meranti	
		English Oak*	
		Light Red Meranti	

Source: Strength grouping of Malayan timbers (Burgess, 1956).
*(*) denotes foreign timbers.*

However, this method was found to be inadequate for many purposes and as more comprehensive strength data were accumulated, it was possible to derive more accurate strength properties of Malaysian timbers. Engku Abdul Rahman (1972) proposed a strength grouping of Malaysian timbers (Table 2.2) based on their basic and grade stresses. This modern approach of strength grouping was more indicative of the actual strength properties of Malaysian timbers (Wong, 1982).

Basic and grade stresses for the strength groups were formulated using the weakest species in the group to determine the group’s minimum basic and grade stresses. The minimum basic and grade stresses of strength group A to D of Malaysian timbers in green and dry conditions are given in Table 2.3 and Table 2.4. Engku (1971) cited that timber varies in strength from species to species and from the engineering point of view, it is the weakest component of the group which finally dictates the design stresses, it was therefore logical to consider only the weakest species in the parcel. It appears so, that this recourse would penalise the stronger species in the parcel. Under the past circumstances, it was inevitable but even if the proportion of species in a parcel is known, it is usual in timber design practice to specify only the strength group of the timber required.

Table 2.2. Strength groups of Malaysian timbers by Engku Abdul Rahman (1972).

Group A	**Group B**	**Group C**	**Group D**
Balau	Kapur	Bintangor	Damar Minyak
Balau, Red	Keledang	Durian	Geronggang
Bitis	Keruing	Gerutu	Jelutong
Cengal	Kulim	Kedondong	Pulai
Giam	Mengkulang	Kungkur	Sesendok
Kekatong	Merawan	Machang	Terentang
Kempas	Merbau	Medang	
Keranji	Merpauh	Melantai	
Mata Ulat	Minyak Berok	Melunak	
Mempening	Perupok	Mempisang	
Mertas	Punah	Meranti, Bakau	
Nyalas	Rengas	Meranti, Dark Red	
Penaga	Resak	Meranti, Light Red	
Tualang	Tembusu	Meranti, White	
		Meranti, Yellow	
		Mersawa	
		Penarahan	
		Ramin	
		Sepetir	
		Simpoh	
		Nyatoh	
		Terap	

Source: Handbook of structural timber design (Hilmi et al., 1996).

> “The strength of the stronger species in a parcel is doubtless sacrificed but the convenience to the designer, builder and supplier is more than offset the lost.”
>
> *(Engku Abdul Rahman, 1971)*

Table 2.3. Basic and grade stresses of strength groups (green) expressed in Megapascal.

Strength group	Grade	Bending parallel to grain	Tension parallel to grain	Comp-ression parallel to grain	Comp-ression perpendi-cular to grain	Shear parallel to grain	Modulus of elasticity	
							Mean	Minimum
A	Basic	20.60	12.41	17.24	1.72	2.76	13800	8600
	Select	16.55	9.93	13.79	1.46	1.99		
	Standard	13.10	7.86	10.86	1.38	1.55		
	Common	10.34	6.20	8.62	1.29	1.24		
B	Basic	17.24	10.34	13.79	1.03	2.07	11000	6200
	Select	13.79	8.27	11.03	0.88	1.49		
	Standard	10.86	6.52	8.69	0.82	1.16		
	Common	8.62	5.17	6.90	0.77	0.93		
C	Basic	12.41	7.45	9.65	0.69	1.38	9000	5200
	Select	9.93	5.96	7.72	0.59	0.99		
	Standard	7.82	4.69	6.08	0.55	0.77		
	Common	6.20	3.72	4.82	0.52	0.62		
D	Basic	7.59	4.55	6.55	0.41	1.38	5700	3000
	Select	6.07	3.64	5.24	0.35	0.99		
	Standard	4.78	2.87	4.13	0.33	0.77		
	Common	3.80	2.28	3.28	0.31	0.62		

Note: These stresses apply to timber having a moisture content >19%.
Source: Handbook of structural timber design (Hilmi et al., 1996).

Table 2.4. Basic and grade stresses of strength groups (dry) expressed in Megapascal.

Strength group	Grade	Bending parallel to grain	Tension parallel to grain	Comp-ression parallel to grain	Comp-ression perpendi-cular to grain	Shear parallel to grain	Modulus of elasticity	
							Mean	Minimum
A	Basic	25.24	15.14	22.27	1.93	3.24	14800	9700
	Select	20.19	12.11	17.82	1.64	2.33		
	Standard	15.90	9.54	14.03	1.54	1.81		
	Common	12.62	7.57	11.14	1.45	1.46		
B	Basic	19.86	11.92	16.07	1.24	2.14	11700	6600
	Select	15.89	9.53	12.86	1.05	1.54		
	Standard	12.51	7.51	10.12	0.99	1.20		
	Common	9.93	5.96	8.04	0.93	0.96		
C	Basic	14.48	8.69	11.03	0.76	1.45	9300	5500
	Select	11.58	6.95	8.82	0.65	1.04		
	Standard	9.12	5.47	6.95	0.61	0.81		
	Common	7.24	4.34	5.52	0.57	0.65		
D	Basic	9.65	5.79	8.27	0.62	1.38		

Select	7.72	4.63	6.62	0.53	0.99	6600	3100
Standard	6.08	3.65	5.21	0.50	0.77		
Common	4.82	2.89	4.13	0.46	0.62		

Note: These stresses apply to timber having a moisture content ≤19%.
Source: Handbook of structural timber design (Hilmi et al., 1996).

Chu et al. (1997) introduced a new strength grouping of Malaysian timbers in his textbook titled the Timber Design Handbook. In fact, the grouping was actually a collection of several works by FRIM researchers prior to 1997. This new grouping system introduced seven strength groups namely S.G.1, S.G.2, S.G.3, S.G.4, S.G.5, S.G.6 and S.G.7. The new grouping was designed with the aim to subdivide the original A, B, C and D grouping into more groups to efficiently designate each group with the strength properties that was representative of all species in the group. The original grouping was not the accurate representation of the species in each group because each group consisted of large number of species with wide variation in strength.

Table 2.5 shows the list of Malaysian timbers in S.G. divisions. The table is separated into two parts, the upper part is the naturally durable species and the lower part is the species that require treatment. For naturally durable species, sapwood should be excluded, otherwise preservative treatment is necessary.

2.4 ISSUES ON THE TESTING AND GROUPING

Nevertheless, some parts of the industry still favour the older system. Furthermore, the new strength groupings were being criticised based on the fact that some species were claimed to be misplaced in the wrong S.G.. For example, Tembusu was originally in Group B in the A to D grouping system. Despite having density of 865 kg/m^3 at 15% MC, Tembusu was placed in S.G.5 in the same group of Rubberwood and Sepetir.

Table 2.5. List of Malaysian timbers within S.G. divisions.

S.G.1	S.G.2	S.G.3	S.G.4	S.G.5	S.G.6	S.G.7
Naturally Durable						
Balau	Belian	Bekak	Giam	Tembusu		
Bitis	Mata Ulat	Delek	Malabera			
Cengal	Kekatong	Keranji	Merbau			
Penaga			Resak			
Requiring Treatment						
	Dedaru	Balau, Red	Berangan	Alan Bunga	Bayur	Ara
	Kempas	Kelat	Dedali	Babai	Damar Minyak	Batai
	Merbatu	Kembang Semangkok	Derum	Balek Angin	Durian	Geronggang
	Mertas	Kulim	Kapur	Bintangor	Jelutong	Laran
		Pauh Kijang	Kasai	Brazil Nut	Jongkong	Pelajau
		Penyau	Keruntum	Gerutu	Kasah	Pulai
		Perah	Mempening	Kedondong	Machang	Sesendok
		Petaling	Meransi	Keledang	Medang	Terentang
		Ranggu	Meranti	Keruing	Melantai	
		Ru	Bakau	Ketapang	Meranti, Light Red	
		Surian Batu	Merawan	Kungkur	Meranti, Yellow	
		Tualang	Merpauh	Melunak	Mersawa	
			Nyalin	Mempisang	Sengkurat	
			Perupok	Mengkulang	Terap	
			Punah	Meranti, Dark Red		
			Rengas	Meranti, White		
			Simpoh	Nyatoh		
				Penarahan		
				Petai		
				Ramin		
				Rubberwood		
				Sengkuang		
				Sepetir		
				Tetebu		

Source: Chu et al. (1997)

Likewise, Keruing from Group B having density range from 735 to 925 kg/m^3 at 15% MC was subsequently positioned in S.G.5. The grouping procedure was ambiguous and became a dubious issue in the local timber community. In reality, Keruing is renowned for its strength and reliability for structural purposes and often use for roof trusses and other structural applications.

Giam is another paradigm of dubious positioning, from the superior species in Group A downgraded to S.G.5 in the new groupings. The timber is a very heavy hardwood with the density of 865 - 1220 kg/m^3 in air-dried condition. A species of Giam (*Hopea nutans*) had been subjected to the graveyard test to determine its natural durability under exposed conditions. Of the 59 samples tested, in dimension of 50 mm x 50 mm x 600 mm, all were still serviceable after two years. Only 5 per cent of the test sticks were destroyed in the eighth year and 80 per cent of the test sticks were found to be still serviceable after the fourteenth year. Compared to other Malaysian Heavy Hardwoods tested under the same conditions (e.g. Chengal, Balau and Merbau), this particular species of Giam seems to be more durable. The timber has therefore, been classified as very durable under Malaysian conditions (Jackson, 1957). Although the experiment was regarding the durability aspect of the timber, but durability is very much associated with high density and strength. There is a good correlation between natural durability and density, and strength is influenced by density (Leicester, 2001). Besides, the timber served well for all heavy construction, marine construction, ship and boat building (Menon, 1958).

At the moment, there is a necessity to revise the arrangement of the species in S.G.s. However, regrettably there are very limited available archives describing the details of the S.G. classification procedure (Tan et al., 2010).

A theoretical explanation was made by Technical Committee on Strength of Timber, FRIM regarding these arrangements. It was concluded that the sorting of Malaysian timbers from S.G.1 to S.G.7 was based on the basic stress values of each specie, not the ultimate stress values. To discuss the matter further, it is better to review the steps of derivation in obtaining the basic stress values.

The physical testing of timber, either bending, compression or tension will gives the result of the ultimate stress value, namely X. The mean ultimate stresses, X_{mean} and its standard deviation (SD) for the particular type of test conducted were then calculated. Later, the basic stress was derived through the formula;

$$Basic\ Stress = \frac{X_{mean} - 2.33SD}{factor\ of\ \ safety} \tag{2.2}$$

Basic stress is defined as the stress which can safely be permanently sustained by timber containing no strength reducing characteristics. In Malaysia, 1% exclusion limit was applied in the calculation of basic stresses (Hilmi et al., 1996). The derivation of the basic stress was based on the statistical probability of a normal distribution. The choice of this probability was highly dependent on the economics of the country and to the degree on engineering judgement and experience. It was considered fair in Malaysia during that time where timber resources were rich but construction skill was still very low, that a probability of 1 in 100 that minimum strength is exceeded was a reasonable value for most strength properties (Engku, 1971).

One exception was strength in compression perpendicular to the grain mode. Failure of timber under compression load perpendicular to the grain never occurs suddenly and the maximum load is carried indefinitely with increasing deformation (Engku, 1971). Hence the strength was taken at the limit of proportionality. It was therefore reasonable to use a higher probability for this strength property. A probability of 1 in 40 was chosen in this case. To summarise, the minimum stress values for determining green basic stresses were calculated by using the probability values listed in Table 2.6.

Factor of safety included reduction factors for duration of loading and shapes and sizes of the structural members. This single reduction factor also covers such items as accidental overloading, errors in design assumptions, and mistakes in analysis and during fabrication. The factor of safety was applied to the estimated statistical minimum value. Since this factor could not be determined in a scientifically precise manner and it was dependent upon limited information on the behavior of the laboratory test specimens, instead of actual structural component, thus the size of the factor was determined merely from engineering judgement (Table 2.7). This was another reason why the basic stress derivation was highly dependent on the economics and level of engineering of the country.

Table 2.6. Probability values for determination of basic stresses.

Property	Probability value	Formula
Bending	1 in 100	$X_{mean} - 2.33SD$
Compression parallel to the grain	1 in 100	$X_{mean} - 2.33SD$
Compression perpendicular to the grain	1 in 40	$X_{mean} - 2.33SD$
Shear parallel to the grain	1 in 100	$X_{mean} - 2.33SD$
Mean modulus of elasticity	-	X_{mean}
Minimum modulus of elasticity	1 in 100	$X_{mean} - 2.33SD$

Source: Timber Trade Leaflet No.37 (Engku 1971).

Table 2.7. Factors of safety for determination of basic stresses.

Property	Factor of safety
Bending	2.5
Compression parallel to the grain	1.5
Compression perpendicular to the grain	1.3
Shear parallel to the grain	2.5
Mean modulus of elasticity	1.0
Minimum modulus of elasticity	1.0

Source: Trade Leaflet No.37 (Engku, 1971).

Through a quick look at the above equation, it can be stated that low SD will put the basic stress value high. Otherwise, higher SD tends to decrease the value of the basic stress. Statistically, SD value is controlled by the number of specimen involved. The more number of specimens will portrayed a better SD value for a sampling. Referring back to Timber Trade Leaflet No.34, the quantity of specimen for some tests were even less than 10, consequently the value of SD tends to be very high and resulted in poor depiction of the timber true strength (Lee et al., 1993).

While neither the A to D grouping nor S.G. divisions will directly influence the development of the correlation factor, the existing grouping could by some means ease the "similar species" assessment. The procedures to convert small clear strength values to structural size will depend on the timber in the similar strength group. The developed correlation factor is permitted to be applied to other species, provided that the species must be properly and scientifically justified as similar. For example, if the conversion ratio had been developed from Bintangor's specimen, it is then acceptable to apply the same conversion ratio to Gerutu and Melunak. However, Gerutu and Melunak must be demonstrated to be similar to Bintangor beforehand. Referring to the S.G. divisions, those three species are positioned in the same S.G.5. If all the species in the S.G.5 can someway be demonstrated as "similar", than the conversion ratio from Bintangor's specimen will be permissible not only to Gerutu and Melunak but also to the whole species in S.G.5. The similarity statement is mentioned very briefly in a paragraph of the European standard, but almost certainly it refers to resemblance in term of physical and mechanical values (Hugh, 2010). This matter will be discussed in detail in later chapter.

2.5 THE NEED FOR STRUCTURAL SIZE EVALUATION OF MALAYSIAN TIMBERS

Variability, or variation in properties, is common to all materials. Because wood is a natural material and the tree is subject to many constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material (Green et al., 1999). Timber is a difficult material to be characterised due to the wide variation in the strength, not only between different species but also between timber of the same species and even from the same log. The strength and stiffness properties of timber scatter in a wide range. There are two main reasons for the large variability. On the other hand timber is a natural raw material causing a natural variation of physical and mechanical properties of timber products. On the other hand different sawing patterns result in different influences of knots and slope of grain on the strength and stiffness properties (Desch and Dinwoodie, 1996). Knowledge and understanding provide information, where possible, on the magnitude of variability in wood mechanical properties.

There are so many factors that affect the mechanical properties of a timber. They include moisture content, natural defects such as knots and sloped grain, seasoning defects such as check and honeycomb and also the present of wane. Even the grain orientation resulted from sawing also influences the strength of timber. In addition strength is also affected when the timber is attacked by fungus and insect before and during use (Hilmi et al., 1996).

In the utilisation of timber, perhaps the most important issue detracting from its outstanding performance as an engineering material is its inconsistency. In fact, that is the reason for the misconception of timber as the weakest building material. The inconsistency is so great that it was addressed in almost every study concerning the strength properties of timber especially timber for structural purposes.

This study does not intend to elaborate on the factors that contribute to the strength of timber. However, an outline diagram is affixed to illustrate how large the variation is. The figure shows some of the inevitable natural growth defects, defects that occur during processing works and defects obtained due to the various conditions of application. Readers are encouraged to read specifically on each subject to discover deeper concerning the listed topics. Figure 2.2 shows a simplified listing of some of the factors contributing to the mechanical properties of timber. These factors must be taken into account in assessing actual properties or estimating the actual performance of timber products.

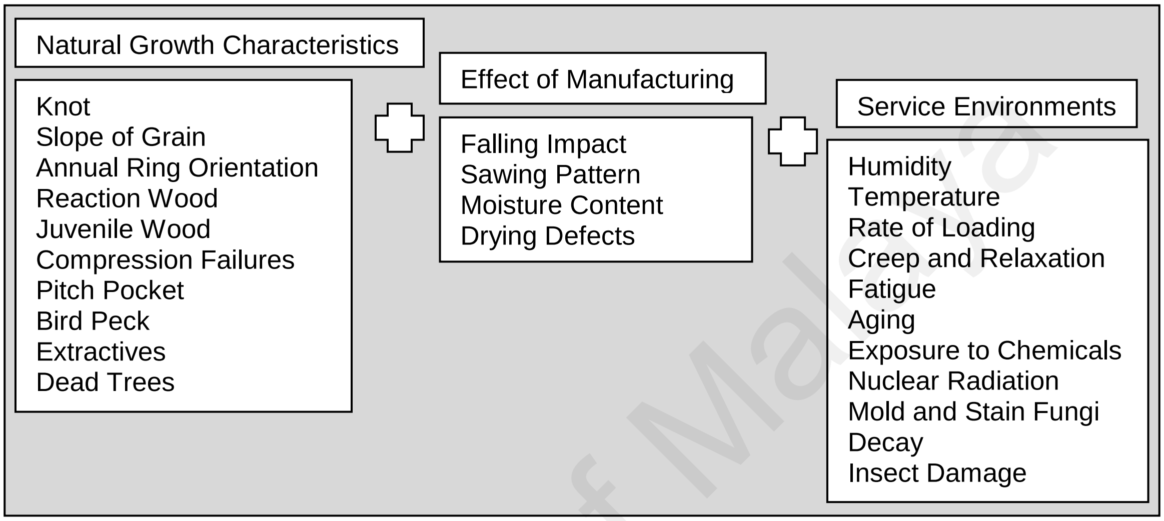


Figure 2.2. Factors contributing to the physical and mechanical properties of timber.

As a biological material, timber shows a large variability on its mechanical properties that turns into an extremely difficult strength assessment. Engineers and designers need reliable and accurate information pertaining to the properties and performances of the timber. Strength and surface hardness of timber are closely related to density, but strength is markedly reduced by grain deviation, knots and brittle heart (Desch and Dinwoodie, 1996; Madsen, 1992). Pieces containing brittle heart are usually light in weight, low in strength and liable to sudden fracture. Small clear wood specimens testing method may have been convenient from a wood scientist point of view. However it cannot provide a reliable basis for structural purposes.

> “If we want to obtain the strength of concrete, we would not rely on a method consisting of testing only the cement, but that is essentially what was done with the timber products. The testing results should, as closely as possible, reflect the structural end use conditions to which the timber products would be subjected.”
>
> *(Borg Madsen, 1992)*

The need to classify timber species by evaluating the physical and mechanical properties of structural size timber has always existed. Because of sensitivity to irregularities of grain, edge knots, notches and other stress risers, it is difficult to realize this superior strength in structural members of commercial timber if it is only based on small clear specimen. The need for precise design criteria for the strength of structural timber or composite timber is important for the effective design and utilization of timber. It is important to have direct measurements of the actual strength of the lumber in the structural size (Ahmad et al., 2010).

Engineers and designers need reliable and accurate information pertaining to the properties and performances of the timber. It is well known that using the results from full size structural timber test was considered to be more reliable to allocate the design stress as to eliminate the risk of stress ratio assumptions. In addition, the values will reflect more on the actual strength of timber in use (Madsen, 1992).

In 2009, Malaysia exported a total of RM19.4 billion worth of timber products. In the same year, the country’s import of timber products excluding furniture amounted to RM1.1 billion. This indicates that Malaysia is not only a major exporter of timber products but is also becoming a significant importer to supplement its domestic timber materials (Anon., 2010). According to New York Times, Europe was Malaysia’s second-largest timber export market after Japan, with RM2.67 billion in sales of timber and timber products in 2009. Table 2.8 points some of the most popular Malaysian timbers in European market, listed by the Malaysian Wood Industries Association (MWIA).

Table 2.8. Species of most popular Malaysian timbers (marked as ◄) in the export market.

S.G.1	S.G.2	S.G.3	S.G.4	S.G.5	S.G.6	S.G.7
Naturally Durable						
Balau◄	Belian	Bekak	Giam	Tembusu		
Bitis	Mata Ulat	Delek	Malabera			
Cengal	Kekatong	Keranji	Merbau◄			
Penaga			Resak			
Requiring Treatment						
	Dedaru	Balau, Red	Berangan	Alan Bunga	Bayur	Ara
	Kempas◄	Kelat	Dedali	Babai	Damar Minyak	Batai
	Merbatu	Kembang Semangkok	Derum	Balek Angin	Durian◄	Geronggang
	Mertas	Kulim	Kapur	Bintangor◄	Jelutong	Laran
		Pauh Kijang	Kasai◄	Brazil Nut	Jongkong	Pelajau
		Penyau	Keruntum	Gerutu◄	Kasah	Pulai
		Perah	Mempening	Kedondong	Machang	Sesendok
		Petaling	Meransi	Keledang	Medang	Terentang
		Ranggu	Meranti Bakau	Keruing◄	Melantai	
		Ru	Merawan◄	Ketapang	Meranti, Light Red	
		Surian Batu	Merpauh	Kungkur	Meranti, Yellow◄	
		Tualang	Nyalin	Melunak◄	Mersawa	
			Perupok	Mempisang	Sengkurat	
			Punah	Mengkulang◄	Terap	
			Rengas	Meranti,Dark Red◄		
			Simpoh	Meranti, White		
				Nyatoh		
				Penarahan		
				Petai		
				Ramin		
				Rubberwood		
				Sengkuang		
				Sepetir		
				Tetebu		

Source: MWIA resource personel (2010).

A model analysis was made on Malaysian export of wood and forest products to European Union (EU) by estimating the revealed comparative advantage indices. The results explained the performance of Malaysian wood exports in competing with other exporters to Europe. The research was using the approach of comparative advantage methodology, indicated that Malaysia has high potential in exporting and marketing the product to EU and in average it about 5 times more advantage than other global exporters. The most advantages are gained through export of sawn timber, builder's joinery and carpentry wood. Correspondingly, the mentioned products are among the highest exports of Malaysia in wood and forest industry (Noor Aini et al., 2008).

One very important and pertinent issue in the marketplace is the extension of the CE mark to cover timber destined for structural use. The letters "CE" are the abbreviation of French phrase "Conformité Européene" which literally means "European Conformity". CE-marking is a manufacturer's declaration that the product complies with the essential requirements of relevant EU health, safety and environmental protection legislation. All timbers for any structural use in Europe (EU-25 plus Iceland, Liechtenstein, Norway and Switzerland), regardless of origin, had to be marked CE as referred in the European standard EN 14081 and classified according to mechanical criterion (Anon., 2006). The CE-mark guarantees that the structural timber meets the product requirements set by the authorities, and that it may be sold freely within the European Economic Area (EEA). Created in 1994, the EEA combines the countries of the EU and member countries of European Trade Association.

The great variety of national requirements for construction products and incorporated in the building regulations in the Member States of the European Union constitute a real barrier to the creation of a truly internal market where products and services should be circulating free. Aiming at solving this problem, the European authorities adopted the Construction Products Directive (CPD) of which the CE marking is the visible result in practice. The CPD requires that all construction products shall bear the CE marking before being placed on the market. With this CE marking, the manufacturer declares that the product complies with all the specifications in the reference documents and therefore is allowed to place it on the entire market of the European Economic Area.

The raw material wood, whether solid wood or wood-based panels, is sourced from all over the world. An American or an Asian producer will therefore be required to affix the CE mark and to comply with the CPD in exactly the same manner in order to get access to the European construction market.

A manufacturer must perform two things to be allowed to make a declaration for a product:

i. The product must be tested in an initial type test (ITT) to determine the performance of the product.

ii. The manufacturer must perform a factory production control (FPC) to ensure that all produced products conform to ITT.

Every product that the manufacturer brings on to the market must be conformed to the ITT. Both the ITT and FPC are defined in a technical specification. This technical specification can either be a harmonized product standard, or a European Technical Approval. Structural timber requirements are defined in EN 14081, and require marking on every piece of timber. The quality requirements are strength classes, some requirements on deformation, fissures, wane, biological features and deviation of dimensions. There is no specific requirement on moisture content for hardwood timbers (EN384).

The harmonised standard EN 14081 has been published and ratified in all four parts, but is subject to transitional arrangements to allow for any changes in national regulations. The period for these arrangements has already been extended, but must end with the adoption of the Construction Products Regulation throughout Europe in 2013 at the latest. Unfortunately, the assessment of this strength prerequisite has not been carried out for most tropical species, including Malaysian timber species. Existing strength data of Malaysian timbers are based on standard mechanical tests of small clear timber specimens as described in the Malayan Forest Record No.13 which was very similar to the methods outlined in BS 373:1957 and ASTM D143-52 (Anon., 1959; Engku, 1971). The CE marking process requires testing based on EN 408 which specifies laboratory method for the determination of some physical and mechanical properties of timber in structural sizes. Thus, this requirement is likely to have a strong effect on future consumption of tropical timbers in Europe and could become a trade barrier.

According to ITTO Council's Trade Advisory Group, CE marking requirement is likely to have a strong effect on future consumption of tropical timbers in Europe and could become a trade barrier for three reasons. Firstly, the large variety of tropical timber species as compared with temperate species would imply the need for extensive and expensive testing work. Secondly, the new requirement would limit the introduction of lesser known species in the market. Thirdly, since testing can only be carried out by laboratories recognized by the EU, this requirement would be a source of major economic constraint to producing countries. Small and medium sized industries face more difficulties to implement the CE marking process due to technical and financial limitations (Anon., 2006).

Several discussions at the national level had been held regarding the possible setback and risk of the structural size timber testing if the assessment is to be executed. The laboratories appointed to conduct the assessment should be concerned on the capacity of staff and facility available. Testing structural size hardwoods timber specimens of 50 mm by 150 mm (2 inches by 6 inches) cross area dimension anticipates the laboratory to be equipped with principal testing machine not less than 300 kN of loading capacity. In general, staff responsible for conducting the tests should possess a high level of understanding of the theory and procedure of the structural size test which actually is the reflection of their experience and qualifications. The governmental organizations such as Malaysian Timber Industrial Board (MTIB) and Malaysian Timber Council (MTC) should be aware of the high expenses needed to procure the samples required to execute the test. Millions of Ringgit has to be invested to fund the testing of over hundred of marketable timber species in large sizes. Furthermore, with more than 3000 species of Malaysian timbers, it is almost impossible to conduct the structural size test for each species (Wong, 1982). Eventually the amount of tested specimens plus remnants from the samples which are not reusable for structural application is just like creating more damages to the timber businesses rather than serving them. Not to overlook the risk of unavailable timber species owing to the statistics of what is still available in the Malaysian forests. Above and beyond, the duration of time needed to accomplish the assessment would be unpredictable.

Throughout the world, the practice of structural size testing for mechanical properties determination of timber had been long-established. The formal stress grading system in the United States got its start since 1902 with tests of both small and structural size specimens (Galligan and Green, 1984). The method for the measurement of modulus of elasticity in structural size bending varies in different parts of the world. In Australia and North America, it is the mid-span deflection or middle point between supports that is measured, which is often referred to as a global measurement, while in Europe the measurement is made over a gauge length in between two loading point of the beam, which can be called a local measurement. By measuring the mid-span deflection, the determination of the modulus of the elasticity should be less sensitive to measurement errors (Bostrom, 1999). Regardless of the standard, either Australian, North American or European methods, the procedure in testing large structural timbers has been essentially the same (Newlin, 1930).

In the European standard, timber strength categories are given in the form of strength classes based on the classes' requirement as stated in EN 338 (please refer Appendix 1). Strength values that determine the corresponding European strength classes for a timber are expressed as 'characteristic values'. These values are derived from the results of structural size specimen tests (Geert and van de Kuilen, 2010; Hugh, 2010). There are only two means to achieve the goal; one is to conduct the destructive structural size test, or, the other way is to manipulate the existing data so that it is equivalent to the properties obtained from structural size test. Fortunately, EN 384 permits derivation of strength properties for full size hardwood species through conversion of small clear specimen, provided that relation between the two is proven.

EN 408 is the absolute reference that specifies laboratory methods for the determination of some physical and mechanical properties of timber in structural sizes. This European Standard explains the test procedures to determine the ultimate stresses such as bending MOE and MOR, tensile strength parallel to the grain, compressive strength perpendicular to grain, etc. In addition, the determination of dimensions, moisture content, and density of test pieces are also specified. The methods apply to rectangular and circular shapes (of substantially constant cross section) of solid unjointed timber or finger-jointed timber and glued laminated timber.

Following testing to this standard, it is intended to derive the ultimate values from EN 408 tests in order to obtain the characteristic values. Characteristic value is generally a value that corresponds to a fractile of the statistical distribution of a timber property. For example, the characteristic value of modulus of rupture in bending is the fractile of 5-percentile and for modulus of elasticity the mean value is the corresponding characteristic value. EN 384 gives the method for determining characteristic values of mechanical properties and density for defined populations of timber. The values determined in accordance with this standard are necessary for assigning grades and species to the strength classes of EN 338.

European standard mentions briefly on the alternative methods of determining the characteristic values of bending strength and modulus of elasticity by converting existing small clear specimens' data. However, the conversion procedure is permitted under several conditions:

i. The method is applied only for hardwood species.

ii. The conversion factor may be derived when both small clear and structural size data are available.

iii. For the small clear data, the number of specimen in a sample shall be at least 40 taken from at least five trees, and the test method shall be the same in all cases.

These conversion factors shall then be derived from ratios of the characteristic values from the structural size data to the mean values of the small clear data. The factors obtained will basically be in form of ratio values and are permitted to be applied to species where only small clear specimen data exist. Characteristic values determined in this way shall be reduced by multiplying by 0.9 (Hugh, 2010).

Thus it is important to understand the relationship of the stresses between small clear and structural size specimens. Each of these properties, however, except for MOE, can only be determined by destructively failing a specimen in a respective designated test and impossible to be retested with the same piece for another test. Thus all of the properties cannot be measured on a single piece and relationships among them can only be roughly approximated (Evans et al., 1984).

A report (Lanvin et al., 2009) presented to the technical group responsible for European grading standards attempts to find a single factor for all structural tropical hardwood species. The paper took structural sized data for twelve species included in EN 1912 and corresponding small clear data fulfilling the requirements of EN 384 (for example minimum 40 results from minimum 5 trees, with results reduced by 10%). A linear function was derived for all species over the range of strength classes D40 to D70. The function was;

$$y = 0.3515x \tag{2.3}$$

Where y is 90% of the characteristic bending strength of full sized specimens and x is the bending strength of small clear specimens. The function had an r^2 value of 0.73. The mean MOE of the small clear specimen was taken as the value for structural size MOE or in brief;

$$MOE_{structural} \big/ MOE_{small\ clear} = 1 \tag{2.4}$$

Stiffness and density values are less dependent on defects so they were taken from small clear data without modification (Hugh, 2010).

Stiffness and density values are less dependent on defects so they were taken from small clear data without modification. This approach simplifies the requirement for “similar species” and looks for an underlying trend among the bending strengths of all tropical hardwoods. The approach is promising, and addresses the central problem of how to incorporate the wide range of hardwood species that are found in the tropics. It was designed to maintain the advantage of using structural sized data where this is available. However, the structural sized data has been collected in variety of ways, so it is debatable whether the predictive value of the function is robust enough for use in structural applications. In particular it is not clear that the structural sized data included poor quality graded timber (Hugh 2010).

A method on comparison study (Geert and van de Kuilen, 2010) of tropical hardwood timber strength classification was conducted using samples of cumaru (*dypterix odarata*). The study investigates the relation of strength properties between full size specimen and small specimen for different growth areas. The average and 5-percentile bending strength values of small clears of cumaru samples from Brazil and Peru gave the same values, although the average and 5-percentile bending strength values of full size specimens showed very different results for the two different sources. There are 2 effects that determine the characteristic strength of full size samples:

i. The average value and the standard deviation of the test samples.
ii. The number of weak specimen that fulfill the requirements for visual grading.

Both effects cannot be predicted by the average or characteristic values of the bending strengths of the small clears, and also not of the small non-clears. When the regression plots between the global modulus of elasticity are studied for the full size and small non-clear specimen it can be shown that for both sizes a good correlation between the global MOE and the bending strength is present. The ratio between the slope of the two regression lines is;

$$0.0092/0.0061 = 0.66 \tag{2.5}$$

This factor which can be considered as the size effect between small and full size, could be used to predict the 5-percentile value of the full size specimen out of the 5-percentile value of the small non clear specimen, independent of the source.

A report on bending strength of six *Dryobalanops* species of Sarawak's timbers showed that the small clear specimens versus full size structural specimens correlated at r^2

= 0.56 in green condition and slightly lower at r^2 = 0.55 in air-dried condition. The study concluded that the possible reason was that structural size samples contain wood defects that could be the major factor affecting their correlation. The suggested best way to express their relationship is through the correction factors through strength ratio. It was calculated that the ratios of almost defect free structural size and small clear specimens of the species were 0.75 and 0.77 at green and air-dried conditions, respectively (Alik and Badorul Hisham, 2006).

However the interpretation from his results is rather brief and did not explain much on the correlation. Furthermore, the MOE relationship between structural size and small clear was not reported, most probably because the MOE for structural specimens was not performed. Based on the plotted graphs, the bending strength relationship of the green and air-dries specimens of the small clear to full size were respectively (Alik and Badorul Hisham, 2006);

$$y_{green}\{structural\} = 0.66x + 49.2 \tag{2.6}$$

and

$$y_{dry}\{structural\} = 0.60x + 78.7 \tag{2.7}$$

2.6 FACTORS TO BE CONSIDERED IN TESTING STRUCTURAL SIZE TIMBER

Data on strength properties of Malaysian timbers were from tests on small clear specimens under green conditions and in some cases under air-dry conditions. The values were the average for the number of specimens involved. Furthermore under normal test in the laboratory only a few minutes were required to load the specimens to failure. In practice, however, structural timbers are of much larger sizes than the small clear specimens and very seldom free from defects. In addition the load may be applied for an indefinite period instead of a few minutes. The moisture contents measured from structural size specimens may be different from those obtained from test specimens in the laboratory. Therefore, a number of factors have to be considered in testing large size timbers.

The procedure in testing large structural timbers has been essentially the same for most of the testing standards. The method is called third-point loading, which consists in loading the beam at two points one-third the span length from each support. The center loading method, which has been used by some investigators, results in giving less influence to injurious defects, such as knots and cross grain, and does not bring horizontal shear into play, as does the third-point loading method, which approximates more nearly practical loading conditions. For this reason, strength tests made by the center loading method give considerably higher results than by the third-point method (Newlin, 1930).

The result of defects, such as knots and cross grain, on strength has been fairly well established and recognized in the basic testing rules. Fully as important as the actual presence of the defects are their size, number, and location in the piece (Madsen, 1992). Obviously, defects will have their greatest effect when at points of maximum stress. In a beam tested under centre loading, the maximum stress in bending occurs at the centre. Defects would have their maximum effect at the centre of the length on the bottom face and also on the lower edges of the vertical faces of the beam. If the defects were located toward the neutral axis and toward the ends, their effect would diminish. Under third-point load, defects would have the maximum effect in the lower surface and edges anywhere between the loads. It is evident that with centre loading the full influence of defects within the middle third of a beam is not obtained.

Careful attention must also be given to such factors as speed of test and kind of bearings at supports and load points. Tests have shown that multiplying or dividing the rate of application of the load by 10 raises or lower the strength by approximately 10 percent. The bearings at the load points require special attention in order to prevent premature compression failure both along and across the grain. This is taken care of in the standard procedure by distributing the load through special bearing plates and curved blocks. In the case of centre loading, the standard bearings result in a calculated bending moment that is higher than the moment actually developed with third-point loading. The calculated moment is developed in the central portion of the beam in spite of the distributing effect of the load blocks.

Size is another important consideration in tests of structural timbers. A large number of bending test results archive showed that size effects in bending are very important (Madsen and Buchanan, 1986). The smaller the timber the higher the stresses developed and the less the influence of seasoning checks. Consequently, it is evident that in order to obtain a true measure of the effect of seasoning checks and of the magnitude of stresses developed in structural timbers in service, it is necessary to adhere largely to a single size of timber for comparison (Newlin, 1930; Thomas, 1931).

It is well known that the moisture content (MC) of wood has a tremendous effect on the strength of timber pieces. Above 30% MC the strength of timber does not alter, but as timber dries its strength increases. The exact MC below which there is an increase of strength is known as the “fibre saturation point” and it is not the same for every species (Thomas, 1931). In structural sizes, however, the development of defects tends to offset any increase in fiber strength that may take place as a result of a reduction in moisture content. Furthermore, structural timbers, even after air seasoning for 1 to 2 years, are only partially dry. The outer shell may be somewhat near an air-dried condition, but the moisture content increases from this point to a practically green condition at the center. This unequal distribution of moisture content in most species used for structural timbers causes a progressive failure and appears to be one of the large factors that prevent so called air-dried timbers from showing any higher strength than green timbers. After many years of seasoning, structural timbers will assume a more nearly uniform moisture content throughout, and, with the exception of additional weakening due to defects, whose effect may be largely missed in testing with center loading, would be expected to increase in strength much as do small clear pieces .

The need for standard procedure is fully demonstrated by the lack of uniformity in early tests made on structural timbers by various timber researchers. The diversified methods used in timber testing and the lack of appreciation of the factors effect has resulted in data of incomparable and questionable value, hence totally unjustifiable conclusions. Nevertheless, the impression should not be gained that standard procedure alone is a solution for all ills in timber testing. As a general rule, any series of tests to determine the influence of such factors as age, preservative treatments, and seasoning require similar tests of control specimens, either full sized or small clear, as a basis for comparison.

Furthermore, since all grading rules take into account certain practical conditions which do not give careful consideration to such factors as density, exact size of timber, and exact size and location of defects, to merely grade the timbers proves relatively ineffective from the standpoint of careful analysis of the data. In other words, it is highly essential that none of the details, such as average moisture content, moisture distribution, and size, number, and location of defects, be overlooked or slighted in any way if results of any significant value are to be obtained. Careful analysis should also be made of the data to see that none of the factors that affect the strength of structural timbers have been overlooked or misinterpreted.

2.7 IMPORTANT PROPERTIES REQUIRED FOR CONVERSION FACTORS

The strength of a material such as timber refers to the ability of the material to resist external forces or loads that tend to change its size and shape. The internal forces within the body will be induced to resist such changes. These forces are called stresses. Thus strength of timber refers to its ability to resist applied forces that could lead to its failure, while its elasticity determines the amount of deformation would occur under the same applied forces, refers to as the stiffness of the timber (Desch and Dinwoodie, 1996). These properties are inherent in the material itself and must be determined by experiment. As a result, several types of tests have been developed to evaluate a material's strength under loads that are static, cyclic or dynamic, extended in duration, or impulsive. These loads may be applied slowly at constant rate which we refer to the inherent resistance of the material as its static strength, or they may be applied exceptionally quickly, when we refer to the resistance of the material as its dynamic strength.

2.8 STRENGTH, ELASTICITY AND DENSITY

The application of a small load to a wood specimen will cause that specimen to deform; the application of additional small loads will cause further deformation of the specimen, it will found that the increments in deflection are proportional to the increment in load. This is illustrated in the load deformation graph in Figure 2.3 as a straight line and can be expressed as;

$$applied\ load \quad \alpha \quad deformation \qquad (2.8)$$

Or

$$\frac{applied\ load}{deformation} = a\ constant \qquad (2.9)$$

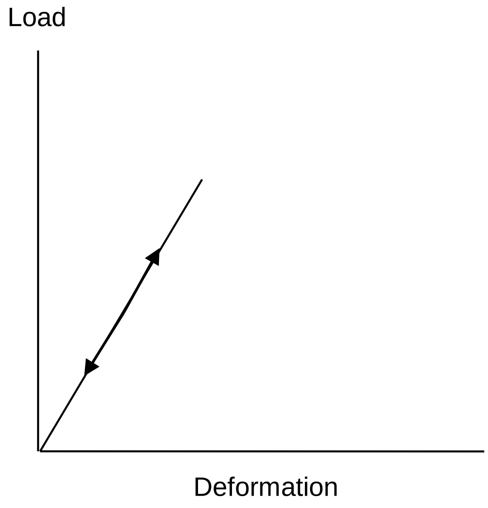


Figure 2.3. Proportional increments of load on piece of wood illustrated as a straight line in load-deformation graph.

The value of this constant will vary with size of the sample, hence it is necessary to express load in terms of the cross sectional area over which it is applied, and deformation in terms of the initial length of the specimen, namely;

$$\frac{load\ (\mathrm{N})}{cross-sectional\ area\ (\mathrm{mm}^2)} = stress\ (\mathrm{N/mm}^2) \tag{2.10}$$

and

$$\frac{deformation\ (\mathrm{mm})}{original\ length\ (\mathrm{mm})} = strain\ (\mathrm{unitless}) \tag{2.11}$$

Stress and strain are denoted by σ and ε respectively. Hence;

$$\frac{stress\ (\sigma)}{strain\ (\varepsilon)} = \frac{load\ (\mathrm{N})}{deformation\ (\mathrm{mm})} \cdot \frac{original\ length\ (\mathrm{mm})}{cross-sectional\ area\ (\mathrm{mm}^2)} \tag{2.12}$$

$$\frac{stress\ (\sigma)}{strain\ (\varepsilon)} = a\ constant \tag{2.13}$$

$$\frac{stress\ (\sigma)}{strain\ (\varepsilon)} = modulus\ of\ elasticity \tag{2.14}$$

The modulus of elasticity (also known as Young's modulus) is denoted by MOE and expressed in units of N/mm^2 or Mega pascal (Mpa). MOE is a material constant characterizing one piece of wood. For homogenous materials, MOE will be similar for other specimens from the same sample but, as will be described later, it will vary for wood. MOE is frequently referred to as the stiffness of wood, a popular term which conveys an appropriate image. However, in material engineering field, the general term of stiffness of material is usually refers to the amount of deformation under applied force with regards to its shape. In general, most engineers view stiffness as a function of both the modulus of elasticity and the geometry of a component (Askeland and Phule', 2006). Strictly speaking, the term stiffness is the product of the modulus and the second moment of area, I (Desch and Dinwoodie, 1996).

$$stiffness = MOE.I \tag{2.15}$$

In the straight-line graph in Figure 2.3, wood will behave in a truly elastic fashion, and the removal of any applied load will result in zero deformation. Meaning to say that loading follows the graph upwards, while unloading follows the graph back to zero, and all the deformation is recoverable. In comparing different timbers, that with the highest slope will have the highest stiffness.

However, above a certain level of loading known as the limit of proportionality, departure from linearity occurs such that for each increment of load there is a more proportional increment in deformation. If an applied load above the limit of proportionality is removed, the specimen will not return to zero deformation, but follows a line lying parallel to the initial linear region and terminating on the horizontal axis at some finite deformation shown in Figure 2.4. Thus, permanent deformation has been induced in the specimen that will take the form of cell crushing, if the load has been applied in longitudinal compression, or cell-wall rupture, if a longitudinally applied tensile load has been applied.

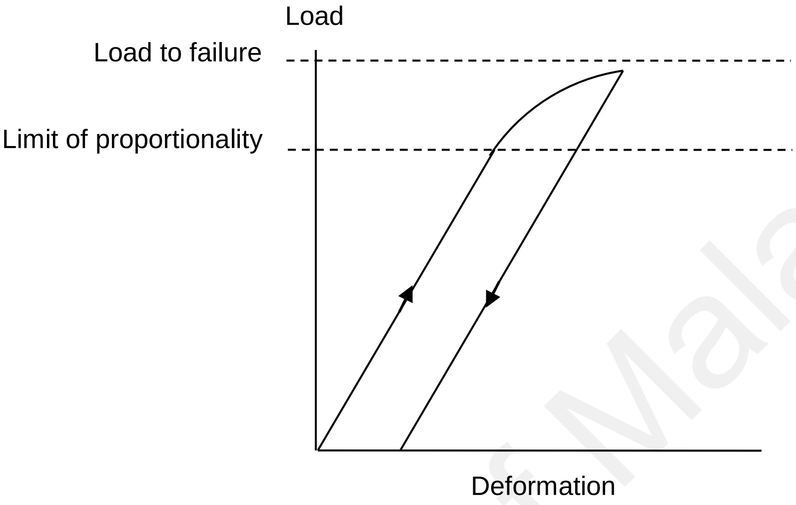


Figure 2.4. Unloading of wood loaded above the limit of proportionality induced some permanent deformation on the wood piece.

The application of additional load will result initially in more permanent deformation and finally in failure of the specimen. The stress level (load divided by cross-sectional area) at which failure occurs is deemed to be the strength of the wood;

$$\frac{load\ at\ \ failure}{cross-sectional\ area} = strength \tag{2.16}$$

The value of this will depend on the mode of stress application, for example, tension or compression. The limit of proportionality also varies with mode of stress application (Figure 2.5). In longitudinal tensile stressing the limit occurs at about 60 to 65 % of the failure stress, while in longitudinal compressive stressing the limit is much lower at 30 to 50 % (Desch and Dinwoodie, 1996).

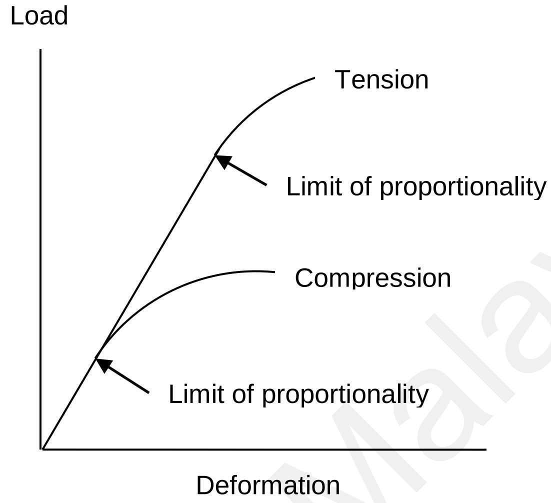


Figure 2.5. Generalized load versus deformation diagram for wood stressed in tension and compression parallel to the grain; the limit of proportionality for each is indicated. (Building Research Establishment, © Crown Copyright)

The strength of wood will vary within mode of load application; the principal modes are tension, compression (both of which can be parallel or perpendicular to the grain), bending and shear. Unlike the position with strength, modulus of elasticity in tension, compression and bending is similar and a common value for all three modes of load application in each of the three principal planes is usually adopted.

Perhaps the single most important property controlling the mechanical performance of wood is its density (Desch and Dinwoodie, 1996). Density is the ratio of mass to volume;

$$\rho = \frac{m}{v} \tag{2.17}$$

where ρ density, in kg/m^3

m mass, in kg

v volume, in m^3

Density is influenced by the amount of wood cell wall relative to the amount of void space in and between the cells. Thus, the main factors affecting density are the size of the cells, including cell wall thickness, the amount of void spaces, and the proportions and distribution of the different cell types (Anon., 2004). In general terms, density is one of the most reliable indicators of strength, as well as several other properties, such as stiffness, joint strength, hardness, ease of machining, fire resistance and drying characteristics.

Care has to be exercised in the application of the equation and the interpretation of results since the density of a piece of wood is determined not only by the amount of wood substance present, but also by the presence of both extractives and moisture. The majorities of timber extractives are usually absent or present in very small amounts, such that they can usually be ignored in the determination of density. However, if the amount of extractive content is substantial, they must first be removed in order to obtain an accurate measure of density.

Density is greatly influenced by the amount of moisture contained in the timber at the time of measurement. The presence of moisture in wood not only increases the mass of the timber, but also increases its volume. Consequently, in order to obtain an accurate measure of density, determination of mass and volume must be carried out at the same moisture content. Generally, in a laboratory, both mass and volume are determined at zero moisture content through drying in an oven at around 103 ± 2 ºC until constant mass is obtained. The formulae to calculate percentage of moisture content (MC) in timber specimen via oven-dried method is;

$$moisture\ content = \frac{m_1 - m_0}{m_0}\ x\ 100\ \% \tag{2.18}$$

where m_1 mass at test, in g

m_0 oven-dried mass, in g

Frequently, density is required at 12 % moisture content, the level at which most timbers are in equilibrium with a relative humidity in the atmosphere of around 65 %. For that reason, density value is normally quoted at a standard moisture content of 12 %. This is referred to as the air-dry density.

2.9 THE ADVANTAGES OF USING TIMBER AS A STRUCTURAL COMPONENT

This study was not designed to quantify the amount of greenhouse gas (GHG) emission of wood compared to non-wood materials. Neither to clarify whether wood production is better for climate change than leaving the forest in its natural state. It calls for experts with adequate knowledge on forestry, chemist and sturdy statistical experience to perform the tasks above-mentioned. However, brief discussion on timber products and their role in the global climate change is necessary to give the factual ideas of the issue when there are many false impressions.

Readers interested in knowing more about the pros and cons of wood products to the climate change in various aspects are advised to refer to Roger Sathre and Jennifer O'Connor (2008). In their assessment, 48 studies were examined, with an emphasis on scientific, peer-reviewed articles. Of these, 34 studies presented original data and analysis on the GHG impacts of wood products. The others summarized or synthesized information from other sources. Twenty studies contained sufficient information to calculate the displacement factor of at least one wood product substituted for a non-wood product. The studies were restricted to analyses of wood material substitution, for example, the use of wood instead of non-wood materials like metals, minerals and plastics. In short, the reviews generally represent the range of expected GHG performance of wood product and its substitutes, depending on the specific products compared and analytical methods employed.

Climate change is a current global concern. The increase in carbon dioxide and other gases in the atmosphere have been associated with global warming and the greenhouse effect. The term ‘greenhouse effect’ is actually a natural occurrence. Combinations of gases in the Earth’s atmosphere are known as greenhouse gases. These include carbon dioxide (CO_2), methane (CH_4), water vapour and nitrous oxide (N_2O), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). These gases form a shield around the Earth. Sunlight passes through the Earth’s atmosphere and is then reflected back into space. Some of this reflected light will be trapped by the greenhouse gases (Anon., 2008).

It is important not to confuse the natural greenhouse effect, without which the Earth’s mean temperature would drop to around 15°C to 18°C, with the contribution mankind is making to intensify the effect, largely through rapidly increasing CO_2 emissions. At least 60% of climate change can be attributed to CO_2 emissions resulting from human activities, mostly the burning of fossil fuels, which contributes 6 billion tonnes of carbon emissions annually. Just to contain CO_2 concentrations in the atmosphere to their current levels would require a reduction in global emissions of more than 40%. As 85% of the energy necessary to run our societies comes from fossil fuels, a reduction in emissions of this order would involve politically unacceptable cuts in our energy consumption (Anon., 2000).

Today, we are faced with shocking world events such as earthquakes, flash floods, cyclones, and droughts, to name just a few, which are becoming more regular and more severe. Such incidents cause not only death but also destruction on an immeasurable scale. Malaysia also was affected by those calamities, fortunately not on such a massive scale. Nonetheless, major flooding that occurred between December 19 and 26, 2006, affecting most of the southern states of the Peninsula, and recurrence of flooding in January 13, 2007, just two weeks after the first flooding, are of concern. Also, back on August 10, 2005, Malaysia was almost choked by smoke from forest fires occurring in our neighboring country, Indonesia, which resulted in a high air-pollutant index. Incident after incident confronting human beings worldwide serve to remind us how delicate is Mother Nature and how crucial it is to have preventive rather than corrective measures established. In brief, things will never be the same.

According to the International Institute for Sustainable Development, a major cause of various catastrophes is the build-up of greenhouse gases, especially CO_2, in the atmosphere. These gases have resulted from the use of coal, gas, and oil throughout the past 200 years. Another contributor to global CO_2 is the businesses sector, which is said to consume a huge amount of energy for space-heating, transport, and lighting. As a general rule, emissions of the various GHGs have further contributed to the rise in temperature that leads to global warming (Norini et al., 2007).

There are two ways to reduce CO_2 in the atmosphere: either by reducing emissions, or by removing CO_2 and storing it. These are different approaches, reducing ‘carbon sources' and increasing 'carbon sinks', with the equal intend and amazingly the versatile wood has the unique ability to do both (Anon., 2008).

Plants take in CO_2 from the air through their leaves and use energy from the sun to make food. As part of this process the carbon is then stored or 'fixed' within the stems, leaves and branches of the plant, and oxygen is released into the air. Roughly 50% of the dry weight of plant biomass is carbon with one tonne of carbon representing 3.67 tonnes of CO_2. Timber and other wood products store the carbon dioxide they absorbed when they were growing trees. The larger the area of plantations established and the faster they grow, the more carbon dioxide will be removed from the atmosphere, thus reducing the imbalance in the greenhouse effect. The carbon embodied in the timber will not be released even when a tree has been harvested and processed into timber products. The carbon dioxide is only released again when the plant is burnt or decomposes (Anon., 2008).

The energy used to create the materials that make up a building is typically 22% of the total energy expended over the lifetime of the building, so it is worth paying attention to the materials specified, as well as to the energy-efficiency of the structure. There is no other commonly used building material that requires so little energy to produce as wood. Plastics derived from petrochemicals and metals such as steel or aluminium actually produce greenhouse gases during their manufacture. Even the processes of extracting some raw materials from the ground, such as bauxite for aluminium, result in greenhouse gas emissions.

Forests and forest products have an important role in reducing greenhouse gases. Young, actively growing regrowth forests and plantations take in large amounts of carbon dioxide from the air. Older and mature forests are an important storehouse of carbon. Timber products not only require far less energy to produce than alternatives such as steel and aluminium, but also act as a long-term storage for carbon.

CHAPTER 3

EXPERIMENT METHODOLOGY

3.1 EXPERIMENT OUTLINE

Putting a first step in the development of structural size strength value for Malaysian timber species, European standards were taken as the basis. The goal is to obtain strength classes for each timber group and the overview is illustrated in Figure 3.1.

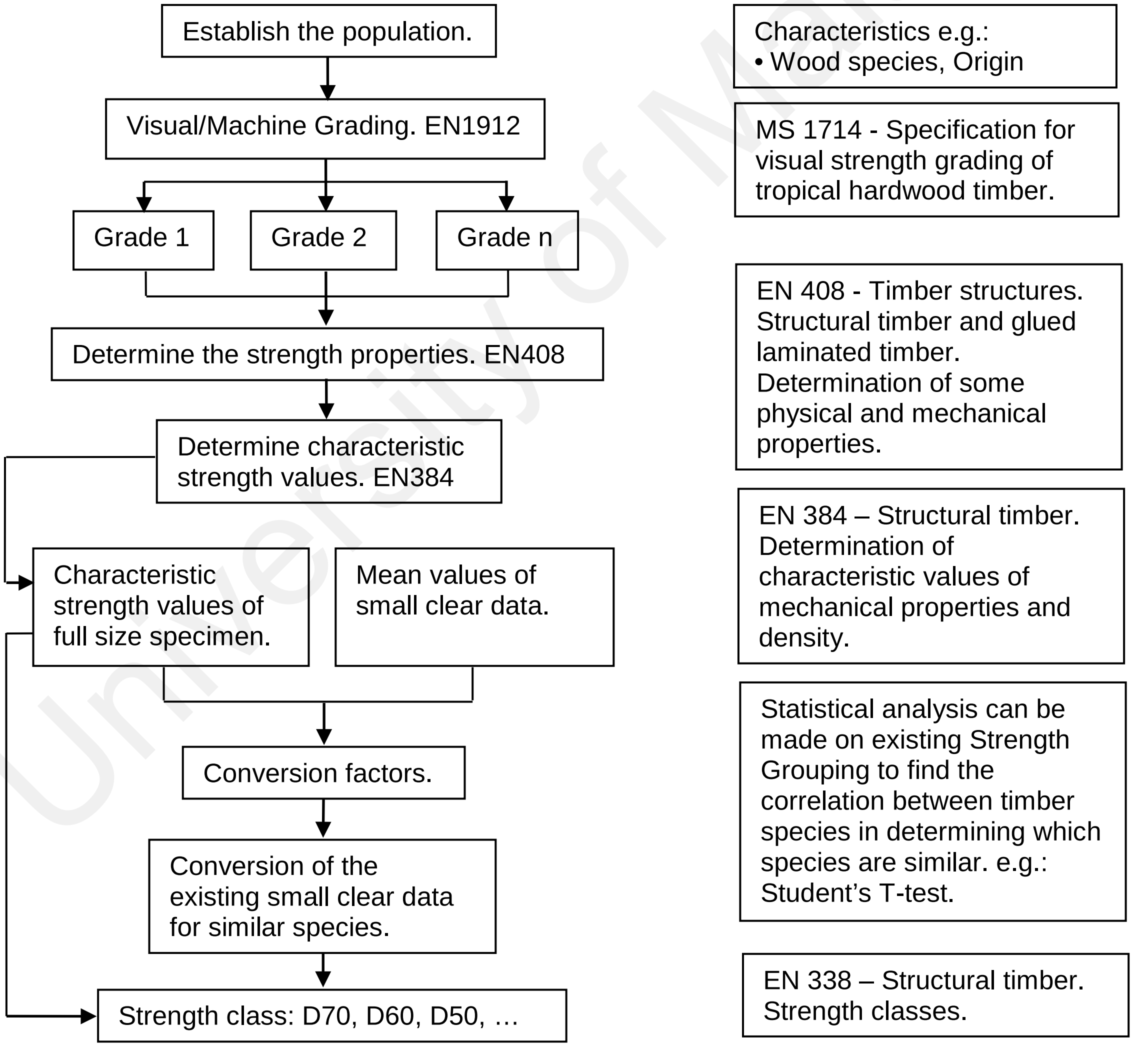


Figure 3.1. Overview of route to obtain structural size timber strength values.

Figure 3.1 shows the flowchart for the experimental works. Initially, a population of sample was selected based on similar species, origin, production time, etc. For this study, Light Red Meranti (LRM) was selected. Next, each specimen was properly graded according to MS 1714 (2003). Destructive test to determine the mechanical properties was conducted based on EN 408 (2003). The methodology will be discussed further in later sub-sections. Results from these tests are referred as ultimate stresses. Characteristic values will be developed from the ultimate values as described in EN 384 (2004). Subsequently, these characteristic values will establish the corresponding European timber strength class for LRM. The European timber strength classes are listed in EN 338 (2009).

This entire assessment concentrates on determining the characteristic values of bending strength, modulus of elasticity in bending and density of the Malaysian timbers in structural sizes, subsequently develop conversion factors between small clear specimen and structural size timber values. Throughout the chapter, some the scope of the study will be discussed and some limitations will be stated. The research materials and experimental setup will be presented in detail.

3.2 CONDITIONING REQUIREMENT OF THE TEST PIECES

The European standard testing method specifies that the tests shall be carried out on pieces which are conditioned at the standard environment of 20±2 ºC and 65±5 % relative humidity. A test piece is conditioned when it attains constant mass. Constant mass is considered to be attained when the results of two successive weighing, carried out at an interval of 6 hours, do not differ by more than 0.1% of the mass of the test piece. However, there is a consideration for timber that is not readily conditionable to the above standard environment, for example hardwood timbers with high density.

Both small clear and structural size specimen testing were performed on Shimadzu Universal Testing Machine AG-100kN at approximately 20˚C environment temperature and 60% humidity. These were the real-time environment conditions during testing, not the environment at which the specimens are conditioned. In reality, conditioning requirement of the specimen as stated in the EN408 Clause 8 is inappropriate in term of practicality due to the temperament of tropical climate. Furthermore, considering the degree of this assessment, budget and facility limitations were the major constraints to conduct the conditioning requirement of the specimens.

Generally, the outdoor and under shed temperature and humidity for Malaysian environment is 29±3 ºC and 75±3 % respectively. As a country located in the tropical climate region, the fluctuation of the environment's temperature and humidity is highly dependable on the local torrential rain. To achieve the European standard's conditioning requirement of the specimen, it is inevitable to conduct the conditioning process in an enclosed space equipped with inbuilt air conditioning system and dehumidifier to control the environment. In addition, with hundreds of timber specimens in structural size, the conditioning process will need immense conditioning chamber to sufficiently place all the stacked samples. Besides, the extent of period needed to condition tropical hardwoods of density ranging from 600 kg/m^3 such as Bintangor to 1200 kg/m^3 of Kekatong will be presumably impractical for this assessment.

3.3 SPECIMEN PREPARATION

The timbers were originated from local saw mills to simulate the actual circumstance in acquiring planks from timber suppliers. The first sampling of 75 planks of mixed species of Malaysian hardwoods was acquired in plank size of 50 mm x 175 mm x 2130 mm (2 inches x 7 inches x 7 feet). The original unprocessed specimen is illustrated in Figure 3.2. Samples were cut into standard length for structural size bending test as mentioned in EN 408:2003 and small clear specimen of 50 mm by 50 mm (2 inches by 2 inches) size according to ASTM D143 - 52. These specimens are illustrated in Figure 3.3. Every significant defect on the specimen was marked and recorded. A second sample of 48 specimens of Light Red Meranti (LRM) timber, properly graded and conditioned, were cut to specimen sizes and tested for both structural and small clear bending test. LRM with density at test ranging from 600 kg/m^3 to 700 kg/m^3 were tested for two nominal sizes, 50 mm by 50 mm (2 inches by 2 inches) and 50 mm by 150 mm (2 inches by 6 inches) cross-section. The results of MOR and MOE for each specimen were calculated and recorded.

Figure 3.2. Original specimen from sawmill of 50 mm by 175 mm cross section of 2130 mm length plank.

Figure 3.3. Specimen size of 50 mm x 50 mm x 750 mm and 50 mm x 100 mm x 1900 mm cut from the original plank.

3.4 SMALL CLEAR SPECIMEN TEST

Test pieces of the static bending test for small clear specimens were loaded in the middle of the sample. This particular configuration is referred to ‘three-point bending’ or ‘centre-point bending’. The actual experimental setup for small clear timber specimen test is shown in Figure 3.4. The bending strength of wood is usually presented as bending modulus of rupture (MOR) which is the equivalent stress in the extreme fibres of the specimen at a point of failure assuming that the simple theory of bending applies. The MOR in three-point bending was calculated based on the following equation;

$$bending\ MOR = \frac{3PL}{2bd^2} \tag{3.1}$$

where P applied load, in N

L bending span, in mm

b width of the specimen, in mm

d depth of the specimen, in mm

For three-point bending, it was customary to calculate the modulus of elasticity in bending simultaneously. Load-deflection graphs were recorded automatically through Shimadzu’s software Trapezium 2. Loads corresponding to increments of deflection were recorded, and the equivalent stresses and strains were determined. The modulus of elasticity (MOE) in three-point bending was calculated using the following equation;

$$bending\ MOE = \frac{1}{4} \times \frac{P'L^3}{\Delta' bd^3} \tag{3.2}$$

where P applied load at the limit of proportionality, in N

L bending span, in mm

Δ' deflection at the limit of proportionality, in mm

b width of the specimen, in mm

d depth of the specimen, in mm.

Figure 3.4. Experimental setup for small clear timber specimen test.

3.5 STRUCTURAL SIZE SPECIMEN TEST

Unlike the static bending test for small clear specimen, the test for structural sized timber employed two points of loading between the support points. The distance between the two loading points was equal to the distance between one loading point and the nearest support. This particular configuration is referred to as 'four-point bending' or 'third-point bending'. EN 408:2003 test arrangement for measuring the MOE in bending is illustrated in Figure 3.5. This method is defined as "local MOE in bending" test set-up. The test piece was symmetrically loaded in bending at two points over a span of 18 times the depth as shown in the figure. The test piece was simply supported with an overhang of approximately 50 mm on each side;

$$overhang \approx \frac{minimum\ \ length\,(19 \times depth) - span}{2\ ends} \tag{3.3}$$

The deflection was measured on one side of the specimen. Small steel plates were inserted between the piece and the loading points to minimize the local indentation. Load was applied at constant rate. The rate of movement was not greater than 0.003 times depth millimeter/second. The maximum load applied was not exceed 0.4 $F_{\max}$.

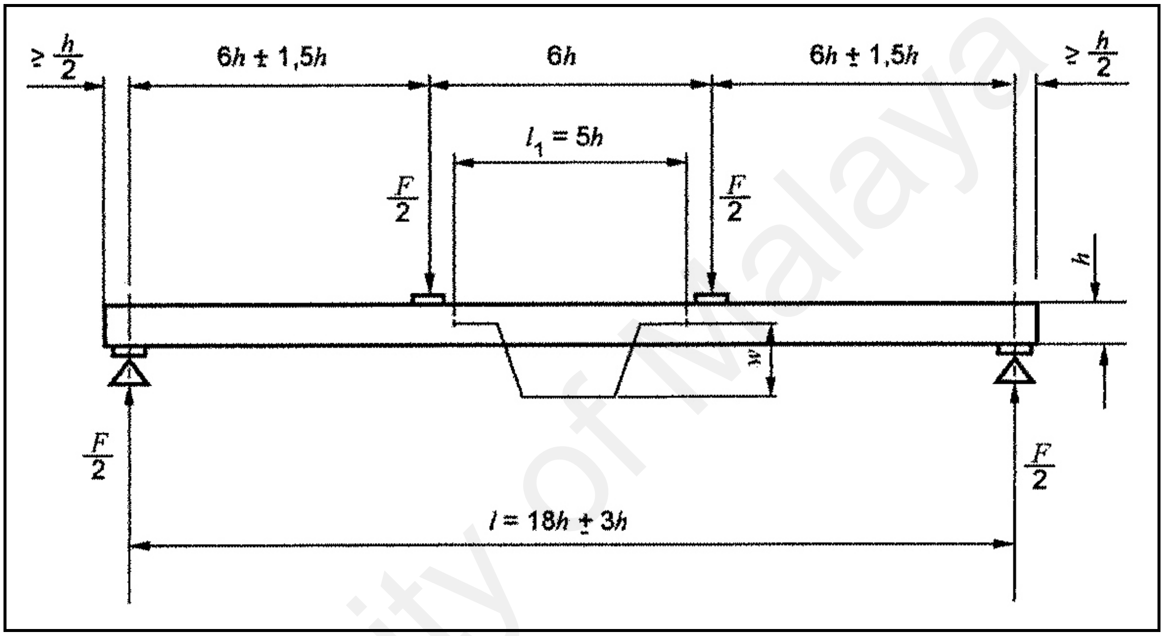


Figure 3.5. Test arrangement for measuring local modulus of elasticity in bending (source: EN408:2003).

Before testing, a critical section was determined in each piece of timber. This section was the position at which failure is expected to occur, based on a visual examination. The critical section was positioned at the centre of the mid span, between the inner load points. The tension edge of the piece was selected at random. The corresponding local modulus of elasticity in four-point bending was calculated from the following equation;

$$MOE_f = \frac{a l_1^2 \Delta F}{16\,\mathrm{I}\,\Delta w} \qquad (3.4)$$

where	a	distance between a loading point and the nearest support, in mm
	l_1	gauge length, in mm
	I	second moment of area, in mm^4
	ΔF	increment of load, in N
	Δw	increment of deformation corresponding to ΔF , in mm

The test arrangement for measuring the global MOE in bending according to EN 408:2003 is illustrated in Figure 3.6. When measuring the global MOE a critical section was selected in the same way as described for measuring the local value. The critical section was positioned between the loading points. The tension edge of the piece was selected at random. Similar to the local MOE test set-up, small steel plates were inserted between the piece and the loading points to minimize the local indentation.

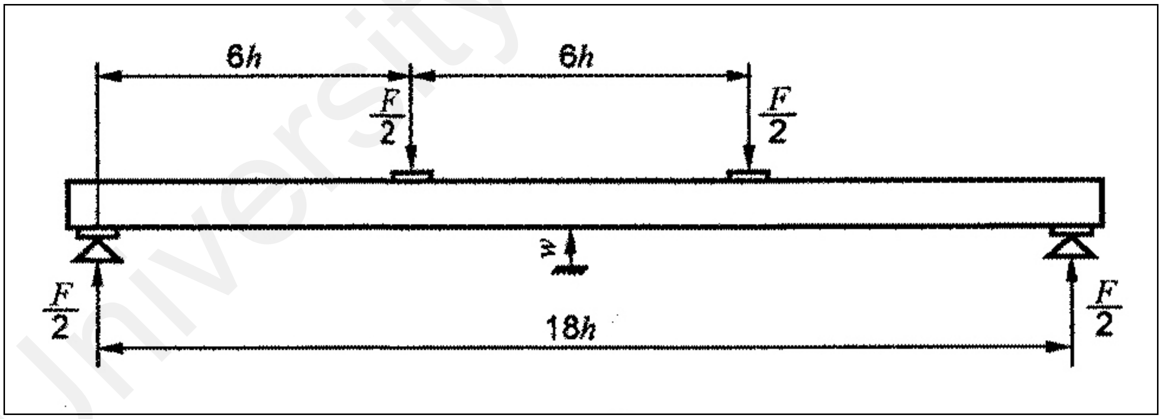


Figure 3.6. Test arrangement for measuring the global modulus of elasticity in bending (source: EN408:2003).

The global modulus of elasticity in four-point bending was calculated from the following equation;

$$MOE_{f,global} = \frac{l^3 \Delta F}{bh^3 \Delta w}\left[\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right] \tag{3.5}$$

where	a	distance between a loading point and the nearest support, in mm
	l	bending span, in mm
	b	width of the specimen, in mm
	h	depth of the specimen, in mm
	ΔF	increment of load, in N
	Δw	increment of deformation corresponding to ΔF, in mm

Figure 3.7. Experimental setup for structural size bending test.

Structural size bending strength was determined by bending the timber specimens to failure. With a similar loading points' arrangement, load was applied at constant loading-head movement adjusted so that the maximum load was reached within 5 ± 2 minutes. The rate was adjusted to reach $F_{\max}$ at 5th minutes. Time of failure and mode of fracture for every test piece were recorded. The modulus of rupture in four-point bending was calculated from the following equation;

$$MOR_f = \frac{F_{\max}\, a}{2W} \tag{3.6}$$

where $F_{\max}$ maximum load, in N

a distance between an inner load point and the nearest support, in mm

W section modulus, in mm^3

The actual arrangement of structural size bending test is illustrated in Figure 3.7.

To recap the overall experiment methodology, Table 3.1 is presented. It shows all the samples involved, number of specimens, size of specimen, bending span, etc.

Table 3.1. Summary of the experiment methodology.

	Sample Group 1		**Sample Group 1**	
Timber species	Mixed hardwoods - Keruing, etc.		Light Red Meranti (LRM)	
Specimen condition	Unconditioned		Kiln Dried (20 – 25)% MC	
Type of tests	Small clear	Structural size	Small clear	Structural size
Number of specimens	75	75	48	48
Size of specimens (mm)	50 x 50 x 762	50 x 100 x 1930	50 x 50 x 762	50 x 150 x 2900
Bending span (mm)	711	1829	711	2743
Expected results	MOE, MOR	Local MOE, Global MOE, MOR	MOE, MOR	Local MOE, MOR
Derivation of characteristic values	No	No	No	Yes
Derivation of correlation factors	No	No	Yes	Yes

CHAPTER 4

RESULTS AND DISCUSSION

4.1 OVERVIEW

This chapter explores on the experiment results and the formulation of the correlation factors. Sub-section 4.2 will be discussing on the ultimate results from mechanical tests. MOE and MOR of small clear and structural size specimens will be evaluated. Both sample group 1 and sample group 2 will be involved in this section.

Then, sub-section 4.3 will be demonstrating a method for grouping Malaysian timber into similar strength properties. Statistical equations will be developed and step by step algebraic calculation will be presented. The discussion will be based on the existing records of mechanical properties of Malaysian timber.

Subsequently, the formulation of correlation factors will be discussed in sub-section 4.4 onwards. This section will be explaining on the derivation of the characteristic values. Only sample group 2 will be concerned in this section.

4.2 ANALYSIS OF EXPERIMENTAL DATA OF MOR AND MOE

Two batches of sample were tested; the first was the green sample and subsequently the kiln-dried and conditioned sample. However, due to limited project funding and timber availability, the species of both samples were not the same. The analysis is more likely to seek for correlation between structural and small specimens regardless of species. But readers should bear in mind that species do affect the correlation, most probably due to density variations which will be discussed in the later paragraphs.

4.2.1 RESULTS FOR SAMPLE BATCH 1 – MIXED HARDWOOD SPECIES

Initially, a total of 75 specimens of mixed hardwood species, unconditioned and ungraded, were tested for both structural size and small clear specimen. Both sizes were cut from the same original plank. Mixed hardwoods with density ranging from 400 kg/m^3 to 900 kg/m^3 were processed into two nominal sizes, 50 mm by 50 mm (2 inches by 2 inches) and 50 mm by 100 mm (2 inches by 4 inches) cross-section. The results of MOR and MOE for each specimen were calculated and recorded. The measurement of structural MOE were taken from centre of the span for global MOE calculation and another measurement from the centre of gauge length at neutral axis from one side of the specimen for determination of the local MOE. The experimental setup for local and global modulus of elasticity measurements is shown in Figure 4.1.

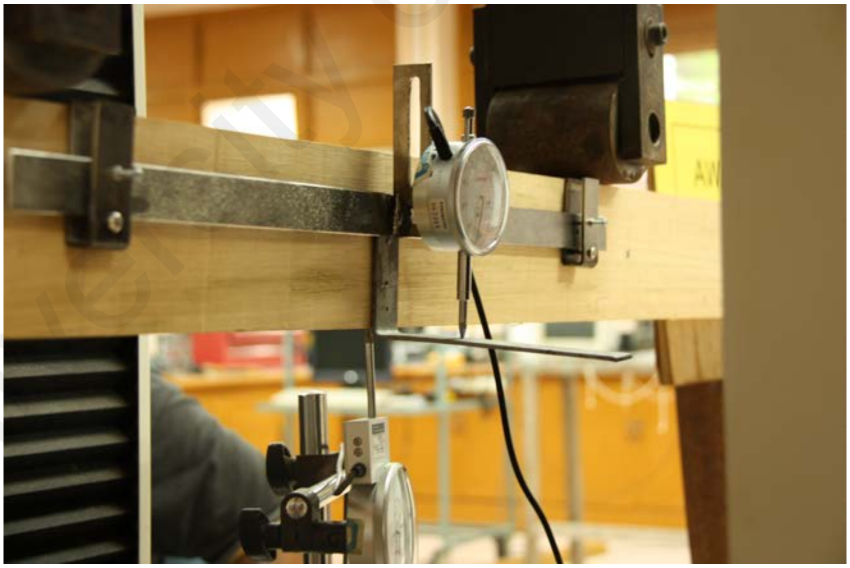


Figure 4.1. Deflection of structural size specimen measured for both local and global modulus of elasticity.

Figure 4.2 shows the differences of MOR values between structural size and small clear specimens. In general, the results indicated that ultimate bending strength of structural size specimens are lower compared to small clear. The small clear specimen method, which was the three-point bending method, resulted in giving less influence of injurious defects, such as knots and cross grain, and does not bring horizontal shear into play, as does structural size specimen method, which was the third-point loading method. Third-point loading method approximates more to actual bending condition. For this reason, strength tests made by the center loading method give considerably higher results than by the third-point method (Newlin, 1930). A large number of bending test results archive showed that size effects in bending are very important (Madsen and Buchanan, 1986).

The linear equation showed that bending strength of structural and small clear specimens correlated by;

$$y[small\ clear] = 0.51x + 27.3 \tag{4.1}$$

Because of the non-homogeneity and anisotropic features of wood, indeed this is only true for prediction and estimation, where in reality it is often inaccurate. The differences between the two sets of data are coherent since mechanical properties variation in timber has been fairly well-known and recognized in the basic testing rules (Thomas, 1931; Desch and Dinwoodie, 1996; Green et al., 1999). However, it was also observed that the differences were uneven and did not compare well to fit a straight relationship. The two measurements were linearly correlated to a degree of $r^2 = 0.40$ (Figure 4.3).

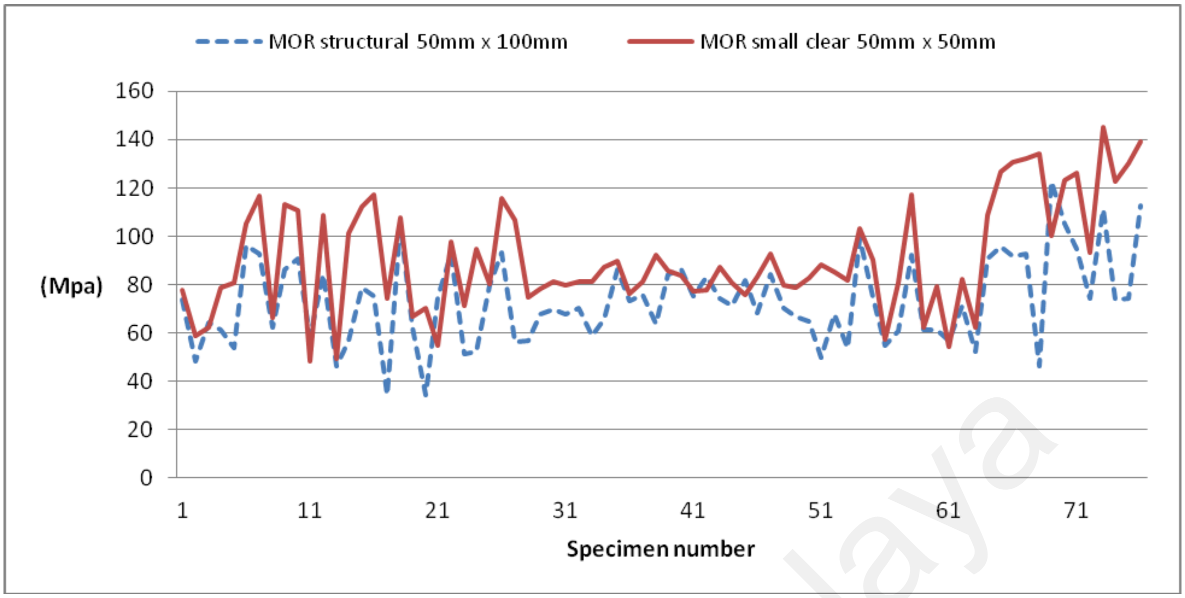


Figure 4.2. MOR of structural size and small clear specimens of mixed hardwoods.

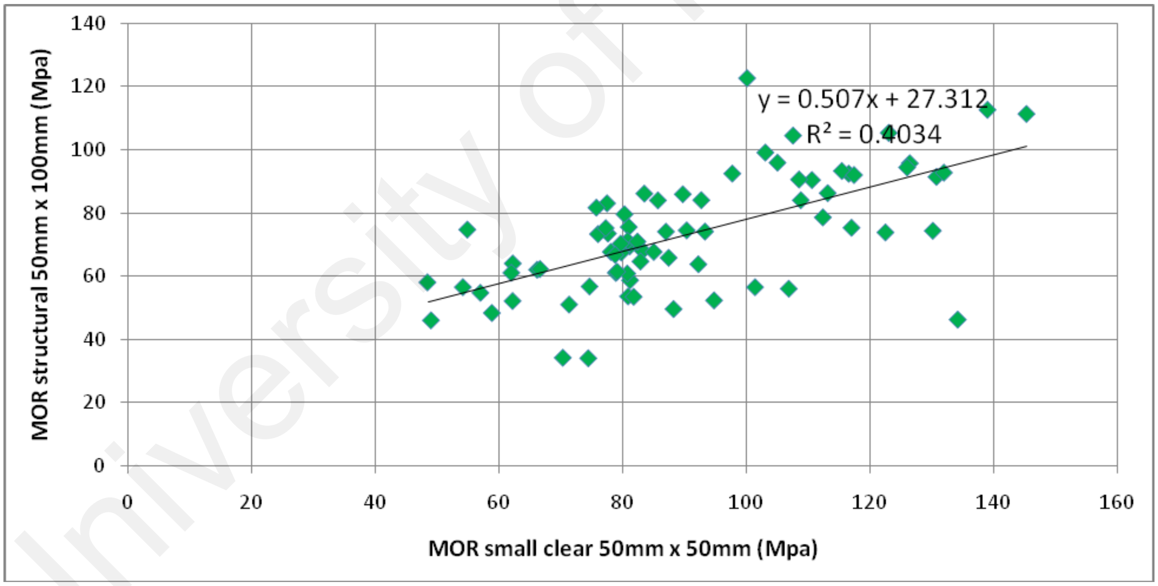


Figure 4.3. Linear correlation between structural size and small clear MOR of mixed hardwoods.

To validate whether linear function is appropriate for this plot, exponential, logarithmic, power and polynomial correlations were also presented using the identical data. Figure 4.4 showed that a better r^2 was obtained for linear correlation when compared to exponential, logarithmic and power correlations. However, Figure 4.4(d) demonstrated that polynomial function best fit the correlation compared to the others.

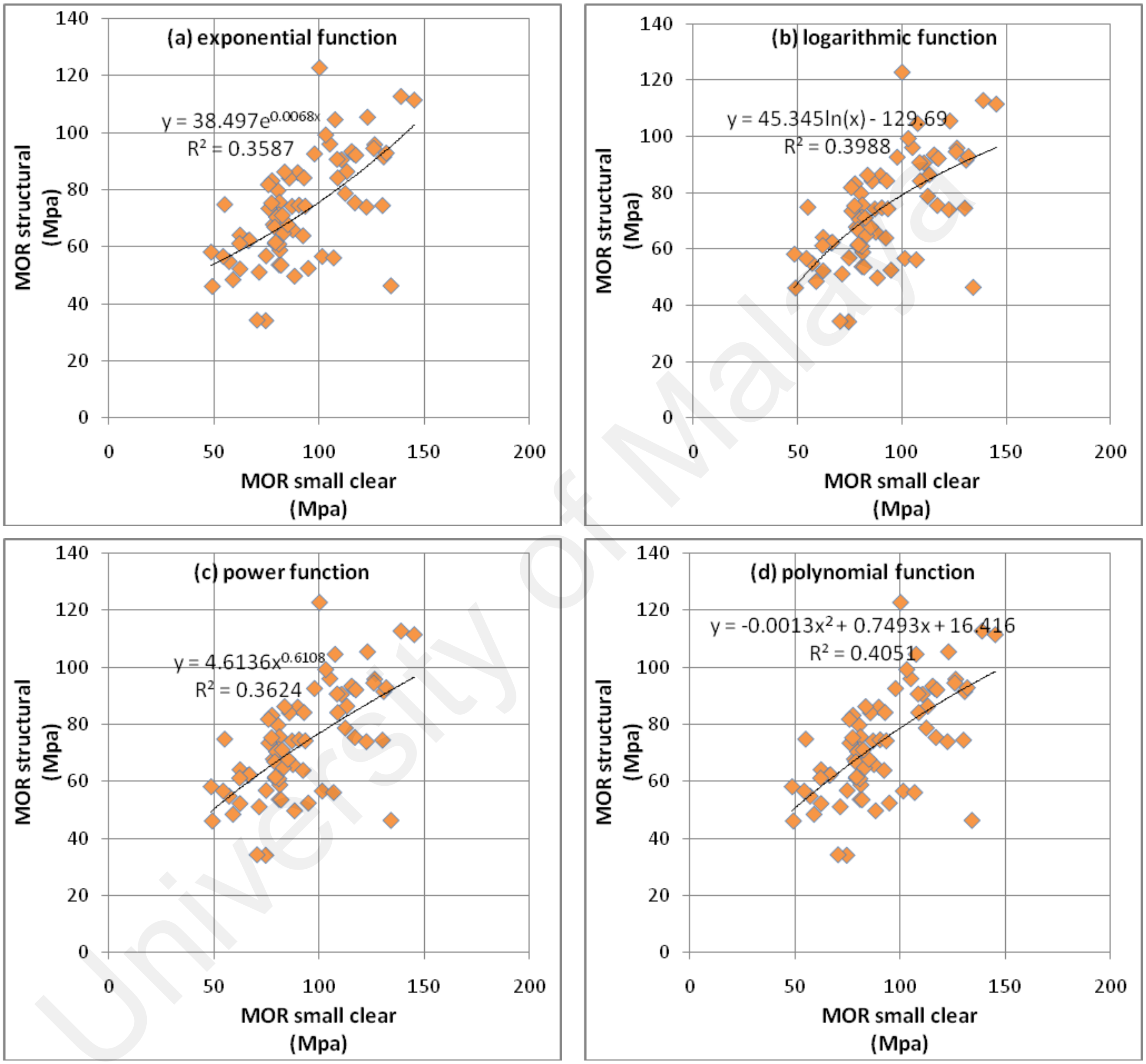


Figure 4.4. Exponential, logarithmic, power and polynomial analyses for correlation between structural size and small clear MOR of mixed hardwoods.

Let's perform an algebraic analysis on the polynomial function from the data;

$$f(x) = -0.0013x^2 + 0.7493x + 16.416 \tag{4.2}$$

$$\frac{df(x)}{dx} = -0.0026x + 0.7493 \tag{4.3}$$

Thus, MOR 2 inches by 2 inches at slopes = 0;

$$\frac{df(x)}{dx} = 0$$

$$x = 288\ Mpa$$

Hence;

$$f(288) = 124\ Mpa$$

$$f(350) = 119\ Mpa$$

$$f(400) = 108\ Mpa$$

It is absurd to say that at strength of 350 Mpa of small clear specimen timber, the equivalent structural size value dropped to 119 Mpa and will dropped further along the trend line. Since the graph consisted of a single variable which was MOR, and since the sizes were fixed, the relationship was unlikely to obtain such values. The polynomial correlation will only reasonable if the effective ranges and limits for the function were established. However that was also impractical since the correlation was meant to determine unknown strength values. Additional comparison between functions in the later paragraph will further verify that the relationship fits a linear correlation.

Besides, the trend showed that the difference of stresses was neither increasing nor decreasing, thus the relationship was more possible to be linear rather than polynomial. To build the degree of confidence in the linearity of two variables, a sort-plot technique is demonstrated (Figure 4.5). One parameter, in this case the structural MOR values, is sorted to an ascending plot. While a trend line is established for the other parameter which is the small clear MOR. Even though the square markers are scattered, virtually the straight line can be observed parallel to the triangle data points. The dashed trend line is a real-time trend line built in a few clicks using Microsoft Excel. The trend showed that the difference of stresses was neither increasing nor decreasing, thus the relationship is more possible to be linear rather than exponential or logarithm. Despite having poor regression value, a linear correlation between structural and small clear specimen MOR is clearly observed in this diagram.

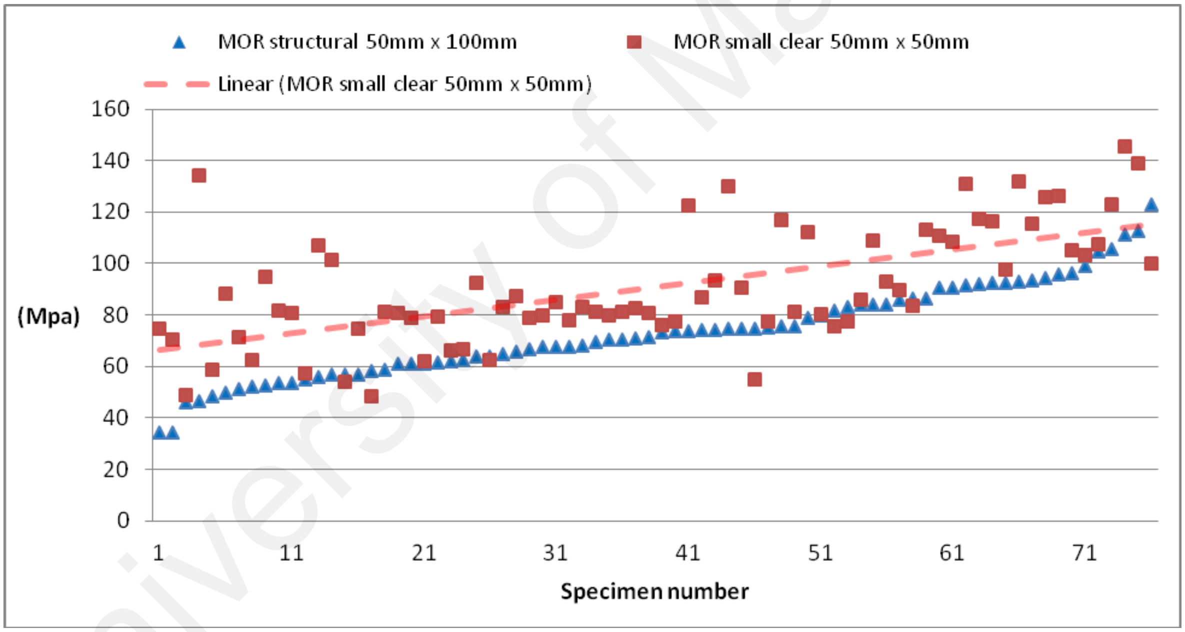


Figure 4.5. MOR of structural size and small clear specimens of mixed hardwoods, sorted in the ascending parameter.

A study by Alik and Badorul Hisham (2006) on bending strength of *Dryobalanops* species of Sarawak's timbers showed that the small clear specimens and full size structural specimens were correlated at $r^2 = 0.56$. The reason for the slightly better relationship in

Alik's work was possibly due to the smaller density range of 630-820 kg/m^3. His results confirmed that generally MOR of small size specimens are higher than MOR of structural size with linear relationship of;

$$y[structural] = 0.66x + 49.2 \tag{2.6}$$

Structural size sample of mixed hardwoods, unconditioned and ungraded means that the population was not only consist of mixed timber species, but also consisted of:

i. Timbers of wide density range.
ii. Timbers of different moisture content.
iii. Timbers containing defects.

Therefore, based on the abysmal correlation in Figure 4.3, it can be understood that strength ratio of small and structural size specimens were greatly influenced by the quality of the timber. Ironically, both density and moisture content are dependent on each other which most probably will results in a complicated study itself. However, further investigation regarding this matter is suggested through sampling of similar density timbers consisting of variable moisture content, or else, sampling of different density timbers with similar moisture content which is much more difficult.

Defects existence such as knots and distorted grain were previously proven to affect the strength of the timber (Desch and Dinwoodie, 1996; Hilmi et al., 1996). It was suggested that the test material should be graded before test for the data to be useful correlation analysis. The test values of the rejects should not be included in the calculation of characteristic values, but they should demonstrate that the grading rules successfully exclude the weak material (Hugh, 2010).

If specimens of similar density (which were marked beforehand and in this case was Keruing) were extracted from the population and plotted for structural size and small clear MOR correlation, better results (Figure 4.6**)** is observed. Although a proper grading was not conducted, a quick visual inspection during the test showed that Keruing specimens contain minor defects compared to others. Dry densities of specimens were measured in the range of 600 - 800 kg/m^3 with MC within 20 - 50 %. Thus, better MOR correlation between structural and small specimens was observed in the sample consists of similar density and with less defects specimens. The two parameters were correlated to a degree of $r^2 = 0.72$.

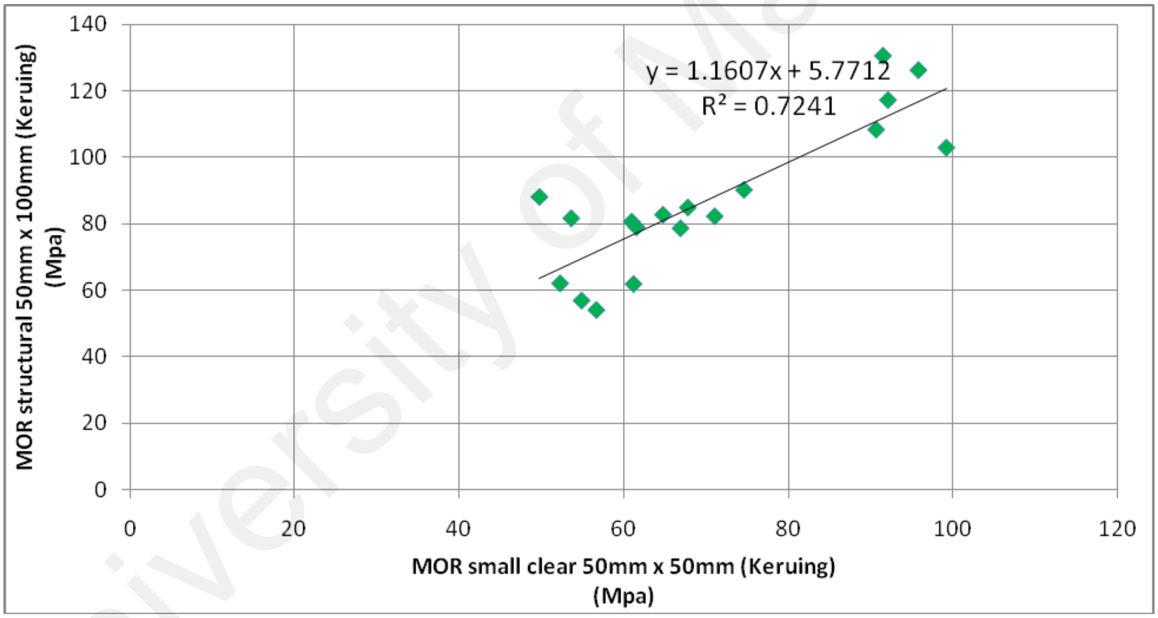


Figure 4.6. Linear correlation of structural size and small clear MOR of Keruing.

An earlier discussion regarding the linearity issue was replicated using only Keruing data. Obviously, r^2 for linear relationship gave a better value compared to exponential, logarithmic and power functions as illustrated in Figure 4.7.

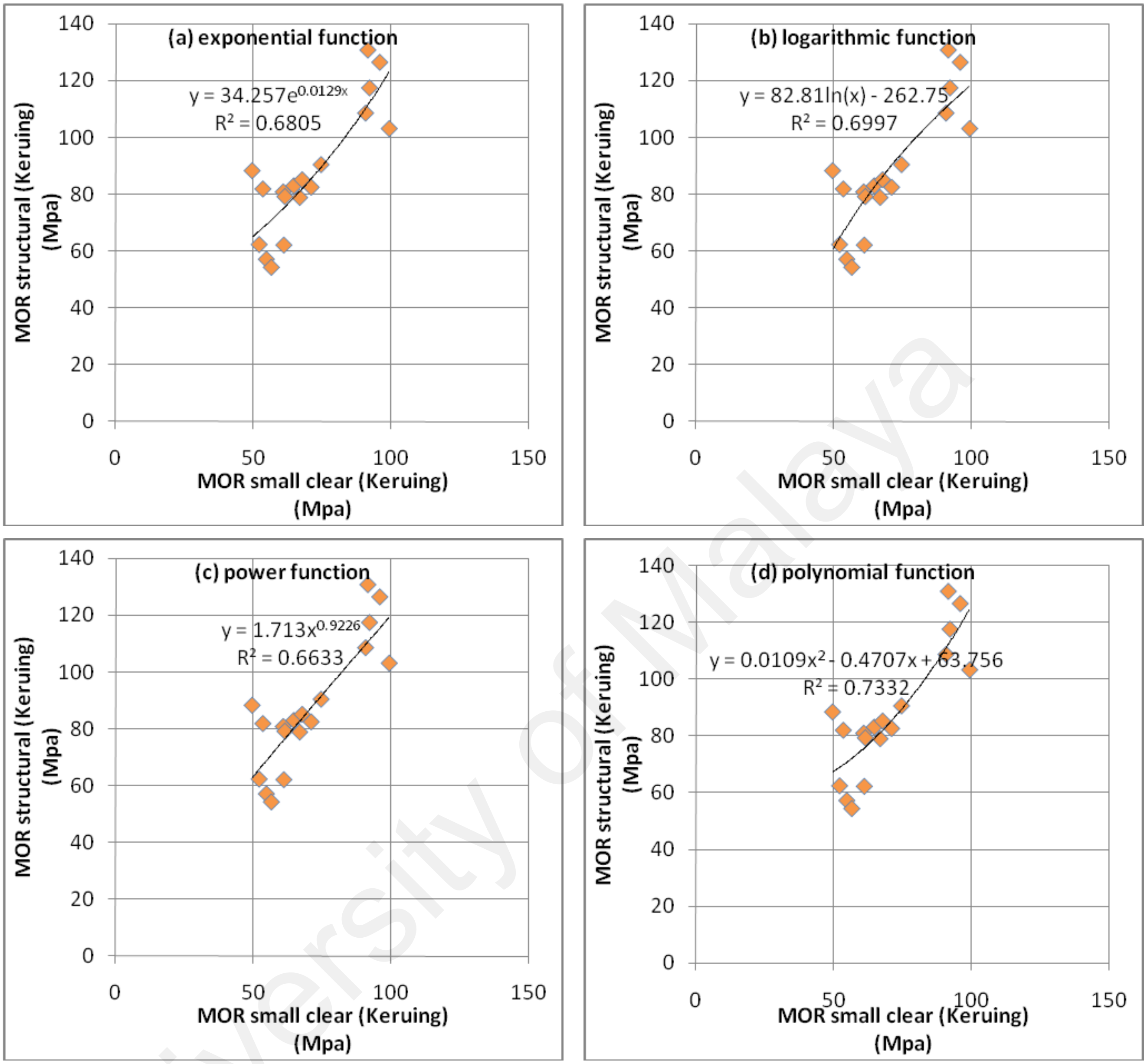


Figure 4.7. Exponential, logarithmic, power and polynomial analyses for correlation of structural size and small clear MOR of Keruing.

Again, Figure 4.7(d) demonstrated that polynomial function revealed a better r^2 than linear. However, referring back to Figure 4.4, the polynomial function earlier was a negative function. On the other hand, the polynomial function in Figure 4.7 was a positive function. It was unreasonable for the same data and range, the values correlated through both positive and negative functions. Therefore, based on the awkward results between Figure 4.4(d) and Figure 4.7(d), a polynomial correlation was improper for these data.

EN 408 described two types of bending MOE measurements; local and global. Correlation graph showed that the values of the local MOE were generally higher than the global MOE. The local and global values in Figure 4.8 show an even correlation throughout the specimens. They were correlated to the degree of $R^2 = 0.84$ (Figure 4.9). Good correlation justified the consistency and reliability of the two measurements. Consistent results were also obtained by Simon et al. (2002). However, there were some values with great deviation between the two MOEs. The fact is that the deflection measurements for local MOE values were excessively small, often less than 1 mm. Hence the method is sensitive to measurement errors. The result was similar to previous study on the two MOEs, which showed that the local MOE was greater than the global (Bostrom, 1999).

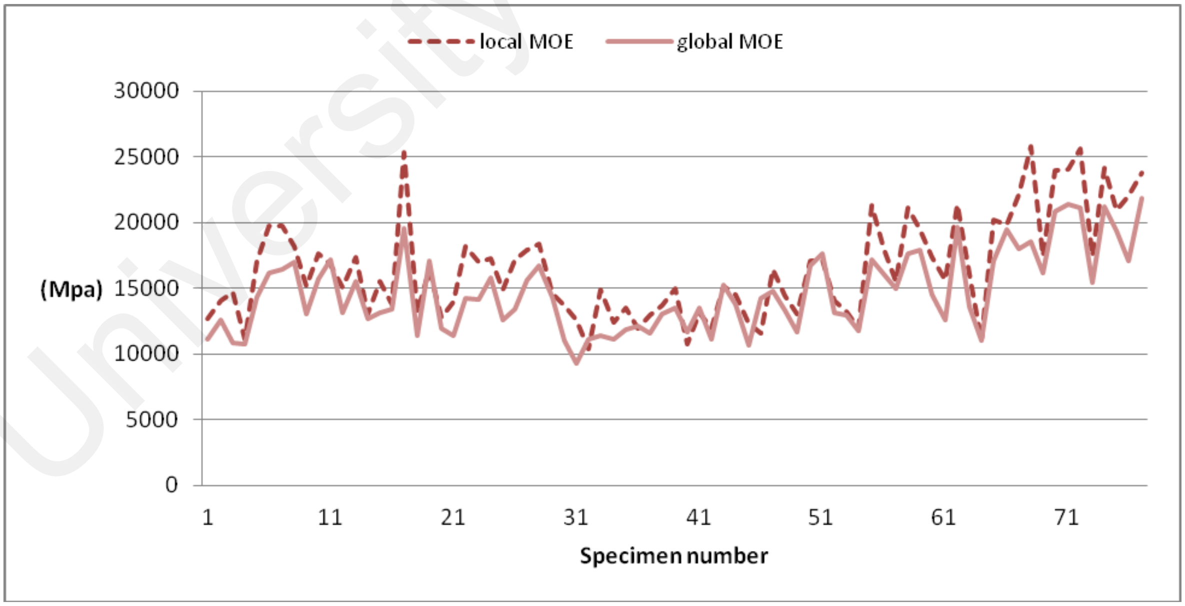


Figure 4.8. Comparison of MOE values of local and global measurement.

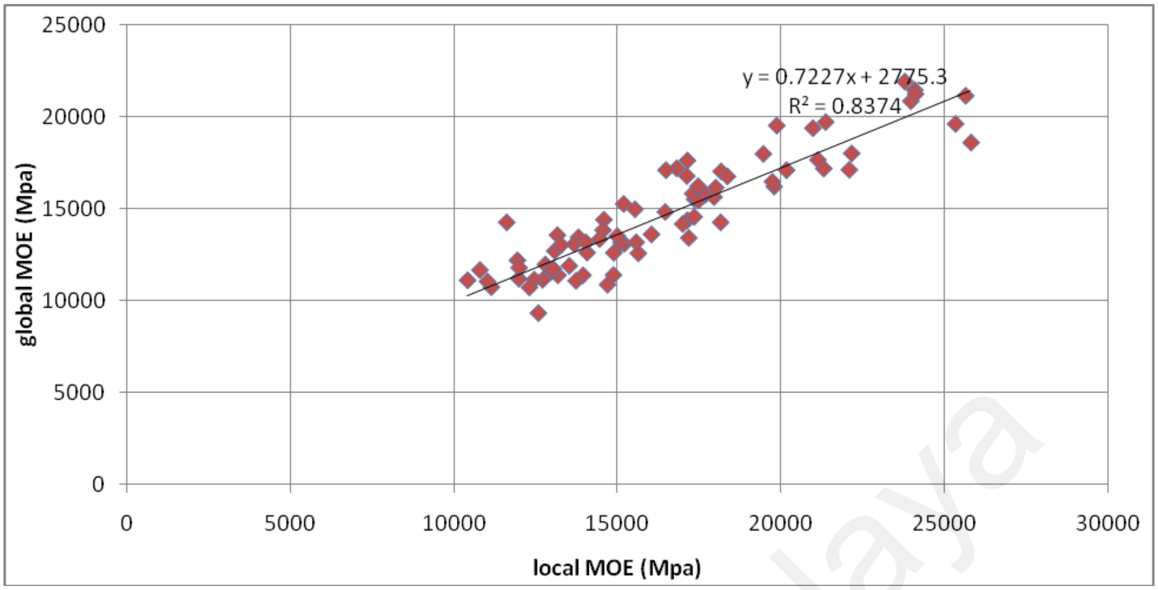


Figure 4.9. Linear correlation between global and local MOE values.

Solli (1996) reported that the risk of inaccurate deflection measurement is much higher for local MOE compared with global. This is due to the different sizes of the local and global deflections since the global deflection is normally about ten times the local. The major source of error in edgewise bending will be linked to initial twist of the timber piece. The effects of twisting will depend on how the deflection is measured, for examples from one or two side at the neutral axis, on the tension or the compression edge. Since the local deflection is just a tenth of the global, any effect from initial twist will be more vital.

Figure 4.10. Twisted specimen resulted in buckling during test.

This was also agreed by Bostrom (1999) as some extreme values were obtained on the local modulus of elasticity. The circumstance was also observed and shows in Figure 4.10. This was possibly because the deformation was only measured from one side, thus twisting of the timber during the test led to erroneous deformation values. Furthermore, the testing jigs were deflected aside due to the buckling and causing a potential damage to the connection. An example is shown in Figure 4.11.

EN 408 is differentiated with the superseded BS 5820:1979 by the method of deflection measurement. According to EN 408, the deflection shall be taken as the average of measurements on both faces at the neutral axis, meaning that two deflection measurement devices are needed. Hence, the uncertainty budget for the errors can be reduced by the average deflection value. Even though, the accuracy requirement for deflection over the gauge length stated in EN 408 will be quite difficult to achieve (Hugh, 2010). Even if the beams were preloaded to a stress of 3 Mpa the influence of initial twist did not dissapper (Kallsner and Ormarsson, 1999). However, it was observed during testing that deflection error can be reduced by placing thin late in gap between twisted plank and support.

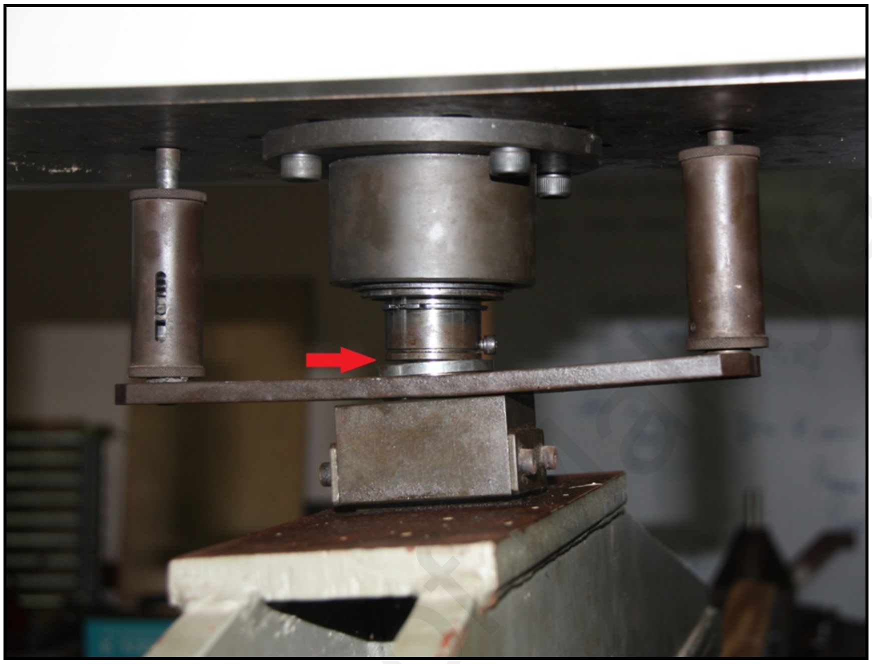


Figure 4.11. The buckling could damage the testing jigs.

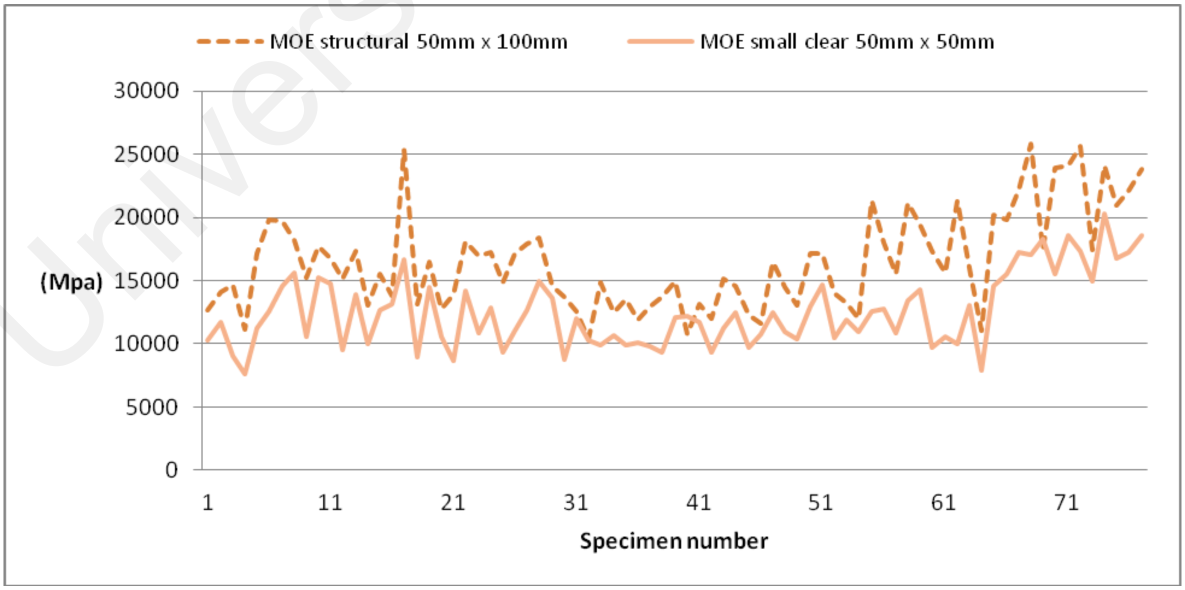


Figure 4.12. Bending MOE values of structural size and small clear specimens of mixed hardwoods.

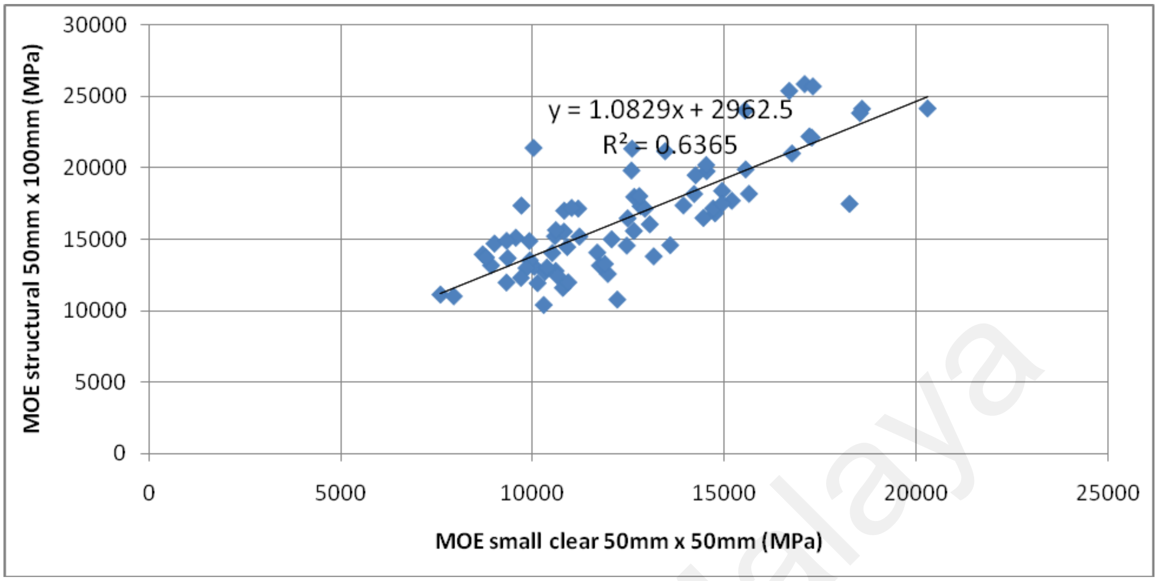


Figure 4.13. Linear correlation between MOE values of structural size and small clear specimens of mixed hardwoods.

Figure 4.12 shows that the ultimate values of full size MOE were higher compared to the small clear. MOE structural and small clear relationship was shown to be more consistent compared to MOR. The two measurements were correlated to $r^2 = 0.64$. The MOE data points for structural size and small clear specimen followed the same trend, which means that the local MOE can be predicted out of the small clear and global MOE. Apart from that, consistent trend between global and dynamic MOE was also observed for tropical hardwoods (Geert & van de Kuilen, 2010).

Results showed that density, moisture content and timber defects have trivial effect on the ratio of small clear to structural size MOE. Thus, MOE values correlated well for structural size and small clear regardless the conditions of the specimens. There were very few studies on full size and small clear comparison for Malaysian timbers to support the MOE result obtained from this assessment. A study conducted by Ahmad et al. (2010)

demonstrated that mean MOE from structural size tensile tests of Kedondong timber was higher than the small clear MOE. Lanvin et al. (2009) took the mean MOE of the small clear specimen as the value for structural size MOE (Equation 2.4). Stiffness and density values are less dependent on defects so they were taken from small clear data without modification (Hugh, 2010).

4.2.2 RESULTS FOR SAMPLE BATCH 2 – LIGHT RED MERANTI

For the second sample, a total of 48 specimens of Light Red Meranti (LRM) timber, properly graded and conditioned, were cut to specimen sizes and tested for both structural and small clear tests. Light Red Meranti with density at test ranging from 600 kg/m^3 to 700 kg/m^3 were tested for two nominal sizes, 50 mm by 50 mm (2 inches by 2 inches) and 50 mm by 150 mm (2 inches by 6 inches) cross-sections. The support used was 18 times the specimen's depth = (18) x 150mm for structural size bending. The results of MOR and MOE for each specimen were calculated and recorded. The measurement of structural MOE was taken from the centre of gauge length at neutral axis from one side of the specimen for determination of the local MOE.

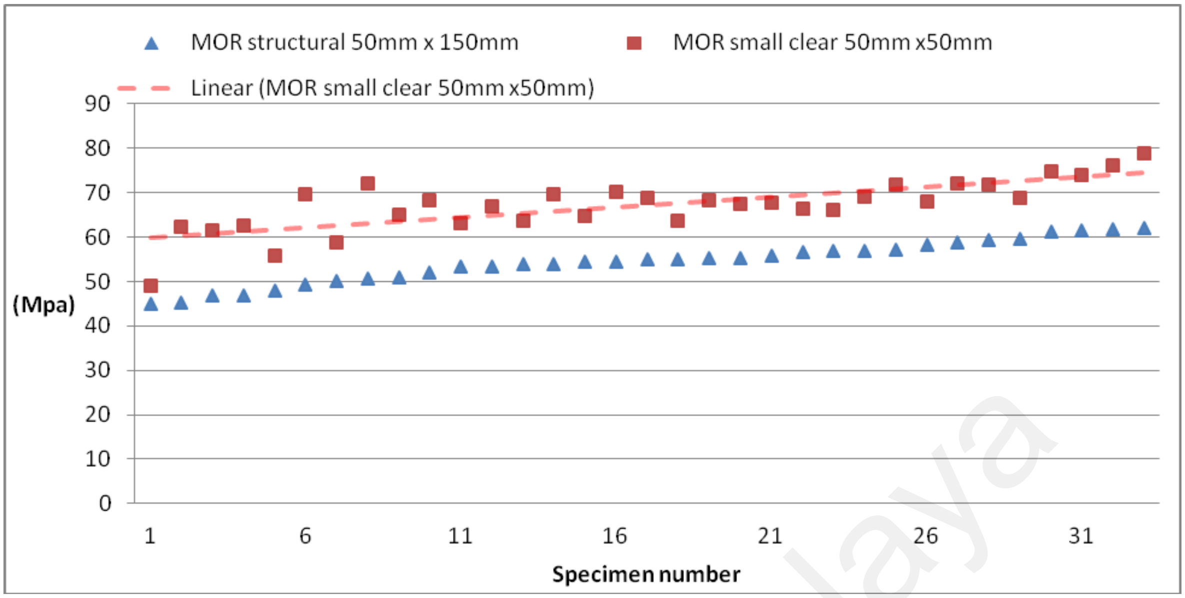


Figure 4.14. MOR of structural size and small clear specimens of LRM, sorted in the ascending parameter.

Again, Figure 4.14 indicates that the ultimate bending strength of structural size specimens is lower compared to the small clear specimens. It was also observed that the differences were consistent and almost smooth to fit a straight relationship. Sorted in an ascending plot, a real-time Microsoft Excel's trend line shows an apparent straight line parallel to the triangle data points. The two MOR measurements are linearly correlated to a degree of r^2 = 0.62 with linear correlation of (Figure 4.15);

$$y\{small\} = 0.64x + 11.26 \tag{4.4}$$

The result was much better than the first sample which consisted of ungraded and mixed hardwood species.

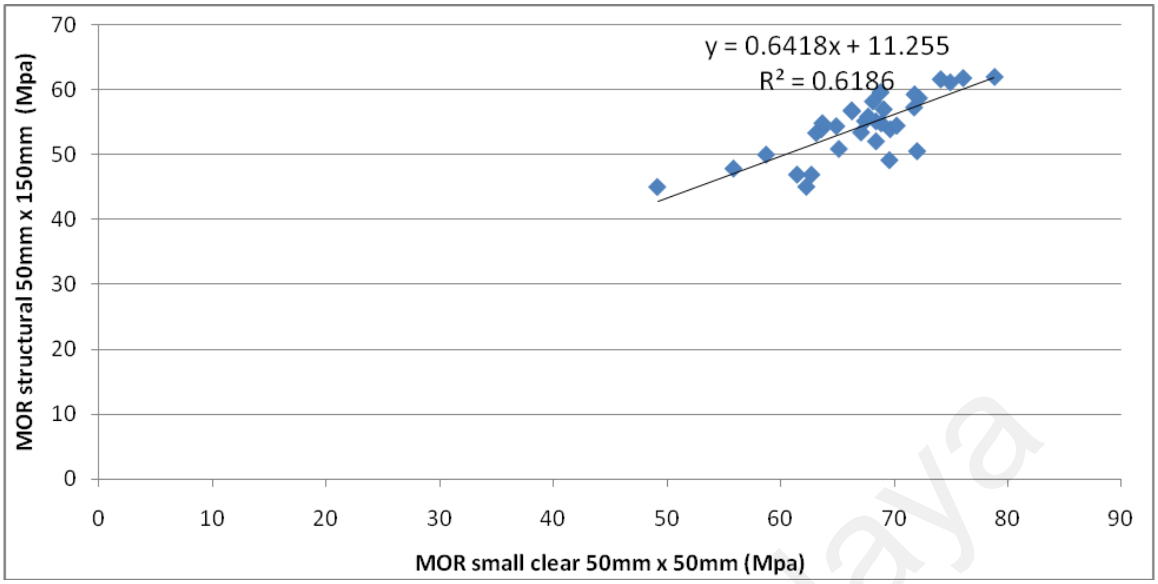


Figure 4.15. Linear correlation of structural size and small clear MOR of LRM.

But even when every precaution has been taken to avoid all factors known to influence the strength of timber, it will still be found that one piece of timber is inexplicably 10% to 15% stronger than another (Thomas, 1931). Until today, the main scientific conclusion for this is because of the genetic variability of timber as a natural material (Desch and Dinwoodie, 1996).

The global MOE was not measured for the second batch of the sample. The comparison between local MOE and global MOE was already shown in the investigation of the first sample. The comparison earlier was an extra analysis since the main objective of the study is to compare the values between small clear specimen and structural size tests. However, it is already proven that local MOE values are generally higher than global MOE values (Figure 4.8; Solli, 1996; Bostrom, 1999). Additionally, it was also shown that good correlation between local and global MOE justify the consistency and reliability of both measurements.

Again, results of MOE values for the second sample showed that the ultimate values of structural size specimen's MOE were higher compared to the small clear specimen's MOE (Figure 4.16). The two measurements were correlated to a degree of $r^2 = 0.57$. MOE of small size specimens was lower than MOE of structural size specimens with linear relationship of;

$$y\{small\} = 0.80x + 6175.1 \tag{4.5}$$

Apparently, r^2 value of 50 mm by 50 mm versus 50 mm by 100 mm was slightly better than r^2 value of 50 mm by 50 mm versus 50 mm by 150 mm. The results showed that size effect is a very important factor in timber bending test (Madsen and Buchanan, 1986). Thus, variations in specimen dimension may also lead to problems in comparing structural and small clear data. As a recommendation for further extensive work, it is advised to use a same structural specimen dimension for the development of the conversion factors.

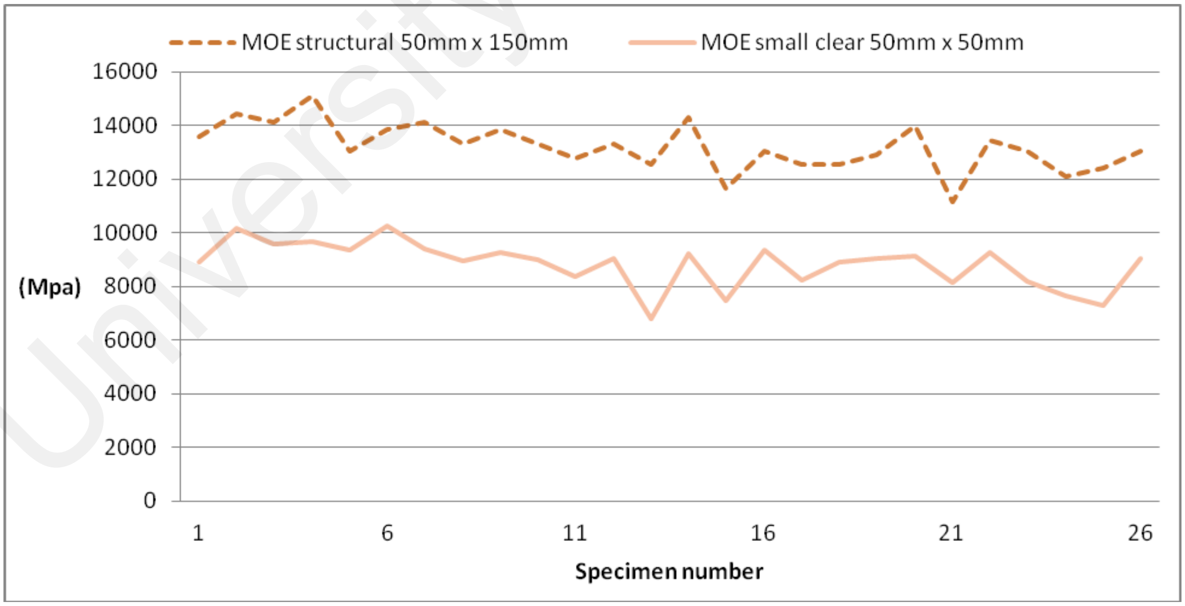


Figure 4.16. MOE comparison of structural size and small clear LRM specimens.

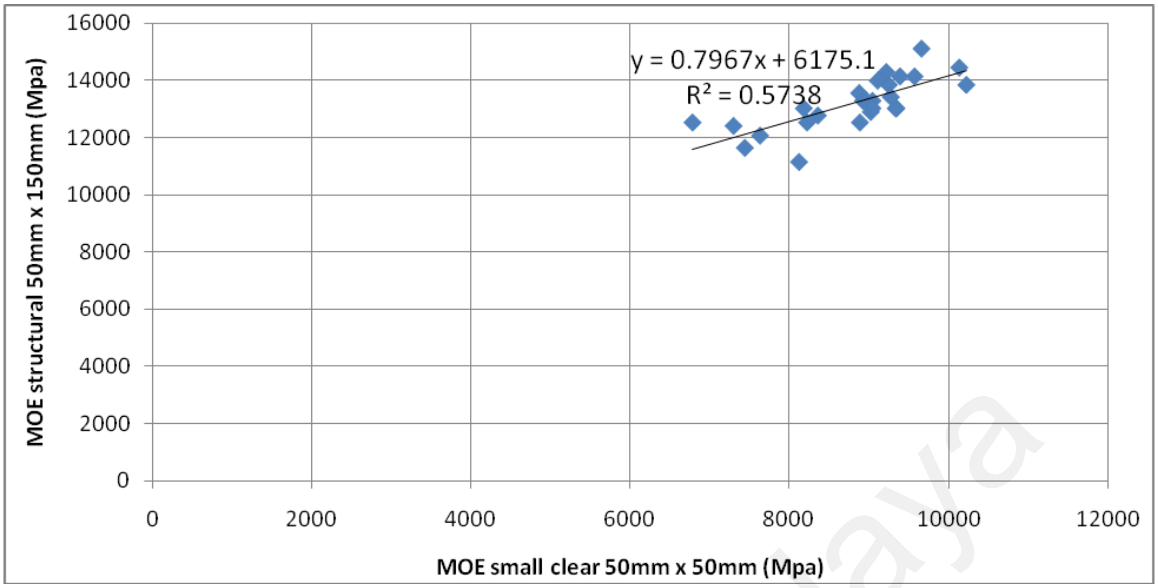


Figure 4.17. Linear correlation of structural size and small clear MOE of LRM.

4.3 GROUPING MALAYSIAN TIMBER INTO SIMILAR STRENGTH

To place the Malaysian hardwood timbers in the strength classes as tabled in EN 338, mechanical properties (such as characteristic MOR and mean MOE) derived from structural size tests must be determined beforehand. Thus there are only two means to achieve the goal; one is to conduct the destructive structural size timber test, or, the other way is to manipulate the existing data so that it is equivalent to the properties obtained from structural size specimen test. In a reference document of the European Standards for structural size timber testing, EN 384, a clause mentions very briefly on the alternative method of determining bending strength and modulus of elasticity of timber by altering existing small clear specimens' data. This chapter focuses on statistical technique for the assessment of grouping tropical timbers into similar strength groups

Two vital properties to be determined from structural size testing are the characteristic values of bending strength and mean modulus of elasticity, and they are allowed to be adjusted from small clear specimen data via the developed conversion factor.

However, stated in the document that the conversion factor may be derived if both small clear and structural size data are available. It is also mentioned in a very general statement that the species should be similar. For the small clear data, the number of specimen in a sample shall be at least forty taken from at least five trees, and the test method shall be the same in all cases.

If the EN paragraph is put in a point-form and arranged processes, the synopsis is:

i. Define "similar" species.
ii. Select a species from "similar" group. (Note that the selected species should have at least 40 specimens taken from at least 5 trees, and the test method should be the same.)
iii. Conduct the structural size bending test for that selected species. (In this part, EN408 document is the key reference.)
iv. Adjust the ultimate MOR and MOE values to obtain the characteristic values. (In this part, EN384 document is the key reference.)
v. Develop the conversion factors.
vi. Applied the conversion factors to the entire species in the "similar species" group.

Therefore it showed how crucial to group the commercial timber into similar species assemblage especially for species with high market demand in European nations. However, the most important issue to be resolved beforehand is; what is the term "similar" referring to? Since the whole assessment is apparently concerning the strength and stiffness of timber, hence the "similar species" term should reflects the similarity in term of mechanical properties among timber species. And since the mechanical properties of the structural size specimen are undetermined, the similarity of the mechanical properties should base on the data of small clear specimen test.

Small clear specimens were defined as specimens with no visible deviation over the specimen’s length. For tropical timber this is hard to distinguish. In practice, even the grain angle deviation is not easy to be determined (Geert and van de Kuilen, 2010). Thus, is it practical to assume that the small size specimens were the corresponding small clear specimens.

One other ambiguous statement is the term “species”. For temperate softwoods it is applicable to conduct the similar group assignment base on species. But with more than 3000 species of Malaysian timbers, it is almost impossible to characterize every tropical hardwood species (Wong, 1982). As a matter of fact, the practice in the timber industry is to describe timber by their trade names. For example, although there are many species of Keruing from all over the peninsular, instead of differentiating them by their vernacular name or botanical name, yet all of them are refer as “Keruing” in the marketplace. Hence a “species” is agreeable to be a group of timber having the same trade name in the market.

Under the older method of grouping Malaysian timbers into strength groups, only the compressive strength is considered. However, in deciding the position of the timber in the corresponding group, bending strength had also been considered. This method divided timbers into four strength group, A, B, C and D (Burgess, 1956). Engku (1972) proposed a more accurate A to D strength grouping of Malaysian timbers based on their basic and grade stresses. This modern approach of strength grouping is more indicative of the actual strength properties of the timbers. Later on, Chu et al. (1997) introduced the new strength grouping of Malaysian timbers in his textbook entitled the Timber Design Handbook in 1997. This new grouping system introduced the seven strength group namely S.G.1 to

S.G.7. However, the grouping procedure was ambiguous and became a dubious issue in the local timber industry since all the related documents are missing (Tan et al., 2010).

Substantial properties of small clear specimen test are available in the Timber Trade Leaflet No.34 such as average density, average values of ultimate MOE and MOR with number of specimen involved and SD for the sampling (Lee et al., 1993). Some of the species were presented in green and air-dried specimen condition and some were only available for green specimen condition. As for the density, it was presented in 3 features; green, air-dried and the specific gravity which was based on weight of oven-dried and volume at test. If the mechanical properties of the Malaysian timbers are available in any other publication or obtained from any conducted laboratory test, they can be added to the list provided that the testing method is the same. In other words, any other data regarding the mechanical properties of timber other than presented in Timber Trade Leaflet No.34 record can be included under the circumstances that the data was obtained from specimen of the same dimension respective to the type of testing.

As discussed in the previous paragraphs, up till this stage, the entire assessment is limited to species of small clear specimen data obtained from at least 40 specimens and from at least 5 trees. However, that does not means that the unqualified species shall never be permissible to be converted. It is just a matter of adding more data to the existing small clear specimen records simply by conducting extra test based on the similar test procedure which was 50 mm by 50 mm by 760 mm (2” by 2” by 30”) static bending test. For example, Tembusu average MOR and MOE were obtained from eleven (11) specimens from two (2) trees (Lee et al., 1993). In order to accumulate Tembusu into the corresponding similar group, an extra 29 number of specimens from another 3 trees should be tested on bending to fulfill the requirements of “at least 40 specimens from 5 trees”.

Readers should bear in mind that the required data is concerning the number of specimen and tree for dried specimen bending test (which gave the results of dried MOE and MOR) and also the number of specimen and tree for dried density determination test. Luckily, the perk is that density test specimens were normally prepared from the same specimen of other tests, namely compression parallel and perpendicular to grain, static bending, impact bending and hardness, thus it can be agreed that the number of the specimens for density determination test is always more than bending test. Hence only the number of specimens for static bending test should be the consideration. Appendix 2 shows a number of timber species that are already fulfilled the prerequisite to be grouped into similar species based on data in the Timber Trade Leaflet No.34 - The Strength Properties of Some Malaysian Timbers. Some information are not available most likely because they have not been tested for air-dried specimen (Engku, 1971) or probably the values were recorded in some other documents.

4.3.1 STATISTICAL TECHNIQUE

A report by Hugh Mansfield-Williams (2010) suggested that a statistically robust method should be implemented to determine whether timbers in comparison are similar or not. This is applicable since the mean values of the strength data are available and can be compared. Several studies on timber strength comparison had been conducted using t-test analysis. Kliger et al. (1995) done a study on the quality of timber products from Norway spruce based on the t-test calculation. Another work by Okai et al. (2004) compared the mechanical properties between branchwood and stemwood of selected tropical tree species of *Aningeria robusta* and *Terminalia ivorensis* by the similar method.

The method for the t-test analysis can be found in most of the mathematic reference books, but for the purpose of this report, it will be discussed in brief. Generally, the t-test assesses whether the means of two groups are statistically different from each other. The formula for the t-test is a ratio which is essentially another example of the signal-to-noise metaphor in research.

$$\frac{signal}{noise} = \frac{difference\ between\ group\ means}{variability\ of\ groups} \tag{4.6}$$

$$\frac{signal}{noise} = t - value \tag{4.7}$$

The numerator is just the difference between the two means or averages while denominator is a measure of the variability or dispersion of the scores. The bottom part is also called the standard error of the difference. To compute it, variance for each group is divided by the number of specimen in that group. These two values are added and square root. The variance is simply the square of the standard deviation. The specific formula is given below;

$$\frac{signal}{noise} = \frac{\overline{X}_a - \overline{X}_b}{\sqrt{\frac{\mathrm{var}_a}{n_a} + \frac{\mathrm{var}_b}{n_b}}} \tag{4.8}$$

$$t - value = \frac{\overline{X}_a - \overline{X}_b}{\sqrt{\frac{\mathrm{var}_a}{n_a} + \frac{\mathrm{var}_b}{n_b}}} \tag{4.9}$$

The t-value will be positive if the first mean is larger than the second and negative if it is smaller. To test the significance, a probability level is set (called the alpha level). In most research, the rule of thumb is to set the alpha level at 0.05. This indicates that five times out of a hundred a statistically significant difference between the means will be found even if there was none. It is also needed to determine the degrees of freedom for the test. In the t-test, the degree of freedom is the sum of the specimens in both groups minus two. Given the alpha level, the degree of freedom, and the t-value, the t-value from the standard table of significance is referred to determine whether the calculated t-value is large enough to be significant. If it is not, then it can be concluded that the means for the two groups is almost the same.

The existing Malaysian timber strength data of small clear specimens were assessed to find the similarity between species; or specifically the similarity in term of mechanical properties between timber groups of the same trade name. Modulus of elasticity in bending for specimens at 15% moisture content was picked as the comparison property since it represents the capability of the material to resist external forces and because it is often one of the primary properties considered when selecting a material for structural design. Furthermore, Alik and Badorul Hisham (2006) showed that a weak correlation was found between small clear and structural size timber in term of modulus of rupture. Thus, strength grouping base on MOE values is more appropriate since the grouping meant to aid structural size timber assessment. However, additional t-test analysis can be done on the other properties such as modulus of rupture in bending or other stress values for enhanced result. In this analysis, only bending MOE value is considered.

As discussed earlier, a “species” is referred to a group of timber having the same trade name in the market. Thus the t-test was carried out based on timber trade name, not on vernacular name or botanical name. For example, the analysis for Red Balau was done based on a single “Red Balau” group representing all Red Balau species. The computation of the combined mean and standard deviation for multispecies timber was based on the weighted mean and reversed SD formula. These analyses however were restricted to data available in Leaflet No.34 and are shown below in details.

The weighted mean MOE for *N* samples of *n* number of specimens is defined via the equation;

$$\bar{x} = \frac{\sum_{i=1}^{N} n_i x_i}{\sum_{i=1}^{N} n_i} \tag{4.10}$$

Reverse algebraic approach was applied based on the basic SD formula to combine standard deviations. The combined SD calculation for *N* samples of *n* number of specimens was based on the principle of the SD;

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{N} (\bar{x} - x_i)^2} \tag{4.11}$$

$$s^2 = \frac{1}{n-1} (\sum \bar{x}^2 - 2\bar{x} \sum x + \sum x^2) \tag{4.12}$$

$$s^2 = \frac{1}{n(n-1)} (n\bar{x} \sum \bar{x} - 2n\bar{x} \sum x + n \sum x^2) \tag{4.13}$$

Since

$$n\bar{x} = \sum x = \sum \bar{x} \tag{4.14}$$

Thus

$$s^2 = \frac{1}{n(n-1)} (n \sum x^2 - (\sum \bar{x})^2) \tag{4.15}$$

This equation will be the combined SD formula which will be demonstrated later. But before that, $\sum x^2$ for each sample will be determined. From the same equation;

$$\sum x^2 = \frac{1}{n} [s^2 n \, (n-1) + (\sum \bar{x})^2] \tag{4.16}$$

Assuming that the dispersion of strength data for each species for one timber can be represented in a normal distribution plot, weighted mean and combined SD are eventually represent by the combination of each bell curve (Figure 4.19). The outcome is a single normal distribution plot that represents all tested species for that particular timber. It should be able to portray the strength dispersion from every original bell curve which is actually the strength data distribution of every specimen from every tested species.

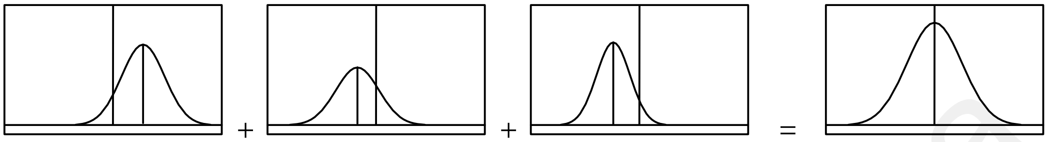

Shorea curtisii *Shorea platyclados* *Shorea singkawang* Weighted mean & Combined SD

Figure 4.18. Weighted mean and combined SD of a multispecies Malaysian timber represented in normal distribution structures.

4.3.2 WEIGHTED MEAN CALCULATION OF RED BALAU

Based on Equation 4.10 and 4.15, example calculation for weighted mean and combined SD of Red Balau species are presented. Data in Table 4.1 were obtained from small clear timber specimen test and were recorded in Timber Trade Leaflet No.34 (Lee et al., 1993).

Table 4.1. Mean MOE, SD and number of specimens of Red Balau timber species.

Species	Mean MOE (Mpa)	SD	n
Shorea guiso	14800	1880	48
Shorea ochrophloia	17000	2660	31

Using the formula given in Equation 4.10;

$$\overline{x} = \frac{\sum_{i=1}^{N} n_i x_i}{\sum_{i=1}^{N} n_i}$$

$$\bar{x} = \frac{(48)(14800) + (31)(17000)}{48 + 31}$$

$$\bar{x} = 15663.29\ Mpa$$

Solving of $\sum x^2$ for species 1 using Equation 4.16;

$$\sum x^2 = \frac{1}{n}[s^2 n\,(n-1) + (\sum \bar{x})^2]$$

$$\sum x^2 = \frac{1}{48}(\ 1880^2[48][47] + [(48)(14800)]^2\ )$$

$$\sum x^2 = 1.07 \times 10^{10}$$

Solving of $\sum x^2$ for species 2 using Equation 4.16;

$$\sum x^2 = \frac{1}{n}[s^2 n\,(n-1) + (\sum \bar{x})^2]$$

$$\sum x^2 = \frac{1}{31}(\ 2660^2[31][30] + [(31)(17000)]^2\ )$$

$$\sum x^2 = 9.17 \times 10^9$$

Hence, the combined SD is calculated based on Equation 4.15;

$$s^2 = \frac{1}{n(n-1)}(n\sum x^2 - (\sum \bar{x})^2)$$

$$s^2 = \frac{1}{(79)(78)}(\ 79\,[1.07 \times 10^{10} + 9.17 \times 10^9] - [(48)(14800) + (31)(17000)]^2\ )$$

$$s_{MOE} = 2453.54$$

The complete results for weighted mean and combined SD calculation are presented in Table 4.2.

Table 4.2. Weighted means and standard deviations of MOR and MOE of some multispecies Malaysian timbers.

Timber Name	MOR (Mpa)	Total number of specimen	SD_{MOR}	MOE (Mpa)	Total number of specimen	SD_{MOE}
Balau, Red (RB)	99.61	79	11.30	15663	79	2454
Durian	77.87	55	14.76	12271	55	3002
Kedondong	81.00	52	8.87	12177	52	1307
Keledang	100.91	46	15.47	14065	46	2497
Keruing	98.34	187	17.17	17645	187	3432
Mempisang	81.15	39	8.37	13923	39	1610
Meranti, Dark Red (DRM)	82.72	93	10.49	12845	93	1619
Meranti, Light Red (LRM)	70.74	91	9.65	12257	91	2019
Meranti, White (WM)	101.19	127	18.54	14808	127	3401
Merpauh	102.21	98	11.32	16686	98	2042
Nyatoh	113.00	50	24.72	16348	50	3225

Note: The original data for each species can be found in Timber Trade Leaflet No.34 (Lee et al., 1993).

4.3.3 T-VALUE CALCULATION OF RED BALAU AND MERBAU

Example calculation for t-value of Red Balau and Merbau timbers is demonstrated below. Values for weighted MOE, combined SD and number of specimens were calculated earlier and presented in Table 4.3.

Table 4.3. Weighted MOE, standard deviation and number of specimens of Red Balau and Merbau timber groups.

Timber Name	Weighted MOE (Mpa)	n	SD
Red Balau	15663	79	2454
Merbau	15400	42	2300

$$t - value = \frac{\overline{X}_a - \overline{X}_b}{\sqrt{\frac{\mathrm{var}_a}{n_a} + \frac{\mathrm{var}_b}{n_b}}} \tag{4.9}$$

$$t - value = \frac{15663 - 15400}{\sqrt{\frac{2454^2}{79} + \frac{2300^2}{42}}}$$

$$t - value = 0.5849$$

t–value from calculation	0.58
alpha level	0.05
degree of freedom	119
t–value from the table of significance	1.98

Hence:

$$t - value \ \ from\ calculation \quad < \quad t - value \ \ from\ the\ table\ of\ \ significance$$

It is therefore can be concluded that Red Balau and Merbau are identical based on modulus of elasticity (MOE) in bending.

The computations were continued in the same manner for the other timbers to find their respective t-value. For multispecies timbers, weighted mean and combine SD were calculated earlier to obtain the representative MOE and SD values for that particular timber group in order to conduct t-value exercise. The t-test was carried out by comparing one timber to the next, rather than comparing similarity between each species in the pack. Meaning, Red Balau was only compared with Ramin and subsequently with Merbau for the t-values rather than comparing it with every species in the list.

The results for t-value analysis of the mean MOE of the small clear bending test data is represented in Table 4.4 below. As discussed previously, the entire analyses were restricted only to data available in Leaflet No.34. Besides, the grouping assessment is limited to data obtained from at least 40 specimens and from at least 5 trees for a single species group (Appendix 2). However Bitis and Mempisang were included in this assessment since they lack only a specimen to be 40 specimens.

4.3.4 RESULTS OF WEIGHTED MEAN, COMBINED SD AND T-TEST

Referring to the results in Table 4.2, it appears that the results of the weighted mean MOR of RB, Kedondong, Mempisang and Merpauh by no means are issues since the differences of mean MOR within species of a same timber are around 10% or less (Lee et al., 1993). Thus, the calculated weighted mean MOR for these timbers are relevant. As for the MOE for these timbers, even though there are differences in the values between weighted mean and species mean, but the gaps are not significant. Thus, for these species, it can be considered that the weighted means of MOR and MOE and combined standard deviations obtained from the calculations are practical.

Table 4.4. Groups of Malaysian timbers having the similar MOE.

E1		E2		E3		E4		E5		E6	
Bitis	23800	Balau	20100	Kapur	18700	Merpauh	16686	DRM	12845	Terentang	7000
		Merbatu	19700	Kempas	18600	Nyatoh	16348	Durian	12271		
		Cengal	19600	Kekatong	18400	Ramin	15900	Meranti Light Red	12257		
				Tualang	17800	Balau Red	15663	Kedondong	12177		
				Keruing	17645	Merbau	15400				
						Meranti White	14808				
						Bintangor	14300				
						Keledang	14065				
						Mempisang	13923				

Note: The value next to the timber name is the mean bending MOE from small clear specimen data.

The differences of the mean MOR between species of Keledang, DRM and LRM vary from 15% to 22%. While the differences in mean MOE between species vary from 24% to 33%. If the differences between weighted values and species values of MOR and MOE for these timbers are calculated, the percentages will be much lower (Lee et al., 1993). Thus, for multispecies timbers known for large strength variation such as Keledang, DRM and LRM, the results of weighted means of MOR and MOE and combined standard deviations obtained from the calculations are reasonable.

On the whole, significant MOR and MOE differences between calculated weighted mean and species mean only seen for timbers known to have great strength variation between species such as Durian, Keruing, Nyatoh and Meranti groups. As a result, large values of combined standard deviation are observed from these timbers. Major differences in the mean MOR and MOE values is apparently an issue since it can directly affect the design and utilisation of the timber. Perhaps results of lower mean values will not agitate the existing structural design calculation, but results of higher values certainly need justifications.

The Malaysian Standard Code of Practice for Structural Use of Timber (MS 544:2001) is based on basic stresses which were derived from ultimate values of air-dry specimen tests (Engku, 1971). The current strength grouping of Malaysian timber, refer to as S.G.1 up to S.G.7 grouping, was also developed based on basic stresses derived from ultimate strength values (Chu et al., 1997). Besides, the previous Malaysian strength grouping known as A to D grouping was also put up based from the same basic stresses (Engku, 1972). For the purpose of deriving these basic stresses, the analysis was based on the weakest component of the group (Engku, 1971) and most probably with the consideration of sufficient sampling of at least 5 trees.

For example, the reference values of MOR and MOE for Keruing are 96 Mpa and 17,100 Mpa respectively, based on the ultimate stresses of *Dipterocarpus baudii*. Likewise, the reference MOR and MOE values for Durian are 74 Mpa and 11700 Mpa respectively, based on *Durio oxyleyanus.* Similarly, the reference MOR and MOE values for Dark Red Meranti are 77 Mpa and 12100 Mpa respectively, based on ultimate stresses of *Shore platyclados* (Engku, 1971). Referring to Table 4.1, it is therefore logical to dictate that the weighted mean MOR and MOE of Keruing, Durian and DRM obtained from the calculation are equivalent to the reference values implemented in the MS 544 document.

One important note is that the calculations only involved air-dry specimens. For a better representation of the timber species strength dispersion, it is recommended that more air-dry specimen tests are conducted and more species is added in the sampling. For example, the timber of group Nyatoh was only represented by 2 species of available air-dry data, *Palaquium impressinervium* and *Palaquium gutta,* even though there were 5 species tested in total (Lee et al., 1993). Furthermore, the untested species can become the crucial data in signifying the strength of Nyatoh since they have lower values of green MOR and MOE compared to the two. The issue of the untested species is the same for WM (Lee et al., 1993). Thus, weighted mean values of MOR and MOE of Nyatoh and WM do not reflect the true strength within their species variation. Apparently, Nyatoh and WM have the largest values of combined standard deviation for MOR.

The t-test results showed that from 23 timbers evaluated, they fall into 6 different MOE levels, from the highest value in group E1 to the lowest value in group E6 (Table 4.4). Each group is separated for being unequal through the t-value tests performed. Balau, Merbatu and Cengal are in a similar assemblage in E2. Kapur and the others in E3 are demonstrated to be identical, whereas Bitis having the highest MOE among all was unable to be put in equality with any other and is alone in E1. However, taken as a whole, the arrangement is comparable to the A to D Strength Groups by Burgess (1956) and Engku (1972) which all the above timber were placed in strength group A and B. However the array is not similar for S.G. by Chu et al. (1997) where Kapur and Keruing were placed in much inferior strength groups in S.G.4 and S.G.5 respectively. The possible explanation for this disparity could be due to the different grouping procedure employed by Chu which was not documented appropriately.

It was discussed in the earlier chapter concerning the ambiguous method in the S.G. groupings and how the timber community conflicted. The 7 groups were being criticized based on the fact that some species were claimed to be misplaced in the incorrect S.G.. For example, Keruing with density of 735 - 925 kg/m^3 at 15% MC which initially positioned in Group B was subsequently downgraded to S.G.5. As a matter of fact, Keruing is renowned for its strength and reliability for structural purposes and often use for roof trusses and other structural applications (Menon, 1958). In fact, Keruing dubious position is one of the main reasons for the S.G. argument (Tan et al., 2010).

It appears that group E4 listed the most timbers compared to the other groups. The arrangement is parallel to A to D Strength Groups (Burgess, 1956; Engku, 1972) which put the timbers in Group B and C except for Red Balau which was placed in Group A. This is as well similar to the SG1 to SG7 grouping which the timbers were categorized in SG4 and SG5, except for Red Balau which was placed in SG3 (Chu et al., 1997). The placing of Red Balau in Group A by Burgess and Engku is explainable by referring to the applied methods. Burgess put a minimum compressive stress value of 55.2 Mpa for Group A timbers, and Red Balau compressive stress value of the species *Shorea ochrophloia* surpassed the limit.

Likewise, Engku set minimum specifications of Group A timbers based on basic and grade stresses, again Red Balau exceeded (Engku, 1971).

The results assembled four timbers in group E5, covering the much lower MOE values. Again, the similarity was recorded in A to D strength grouping which the timbers were sorted in Group C (Engku, 1972). Besides, the arrangement is the same by Chu et al. (1997) which put the timbers in SG5 and SG6. However, there is a slight difference in A to D grouping by Burgess (1956) whereby Durian was located in Group D. This could possibly implies that during the time of Burgess, only the lower strength of Durian species, *Neesia altissima* was tested and through time, the much higher strength of Durian species were also included in the data (Lee et al., 1993). Though, the exact dates for each species was tested could not be determined.

The timber with lowest MOE, Terentang, was observed to be unequal to any of the reviewed timbers. This is most probably because of the very low MOE value of Terentang compared to the others in the list. The similar results were also demonstrated in the older groupings which placed Terentang in the lowest strength group of Group D and SG7 (Burgess, 1956; Engku, 1972; Chu et al., 1997).

It is not a final declaration for the grouping similar timber task. Further improvement is applicable to lessen the number of groups by additional t-test analysis on other properties such as bending MOR or density. Perhaps a different statistical analysis method can be performed to better illustrate the similarity of the timbers. Also, more species can be added to their respective groups through extra small clear timber specimen tests to obtain more small clear data.

However, the results reflects that based on average MOE value, a reliable strength grouping can be established for Malaysian timbers. The pattern of timber strength arrangement through t-test analysis indicates that the outcome is almost similar to the grouping by Burgess (1956) which based on compressive stress and also grouping by Engku (1972) which based on basic and grade stresses. In addition, the pattern is also similar to the listing by Chu et al. (1997) despite the work was being criticized for having dubious procedure (Tan et al., 2010).

Referring to the above table, it can be justified that timbers in E4; Red Balau, Merpauh, Nyatoh, Ramin, Merbau, White Meranti, Bintangor, Keledang and Mempisang are having similarity based on small clear specimens MOE values. Thus conversion factors developed from any of them are valid for every timber in that particular group. For example, conversion factors developed from structural size tests of Red Balau are applied for Bintangor, even without its' structural size test data.

4.4 DERIVATION OF CHARACTERISTIC VALUES OF STRUCTURAL SIZE LRM

Characteristic values are the values that determine the corresponding European timber strength group for a timber. The term "characteristic value" has a specific meaning within the Euro codes. It is a value that is characteristic of some property of the material. Where there is a risk of material failure, the lower 5th percentile of the property is taken as the characteristic value, otherwise the mean value is adopted (Hugh, 2010).

The method for deriving the characteristic values is explained in EN 384 document. Since the specimens in the first sample batch of this study are mixed hardwoods specimens, thus only results from the second sample batch are appropriate for the derivation of the characteristic values. To this point, several important milestones for the structural size timber assessment had been accomplished. In summary:

i. The specimens had been graded visually to select the representative specimens.

ii. The conditioning process of the test pieces was not being done due to practicality and facility factors. However, the specimens had been kiln-dried prior to conditioning and stabilizing the moisture content to the local environment.

iii. Original samples were cut into two sizes; one structural size specimen, and one or several small clear specimens.

iv. Structural size bending test had been conducted and MOR and MOE values for each specimen were obtained. Subsequently, density for every specimen was calculated and recorded. Table 4.5 shows the results of ultimate local MOE, MOR and density from each specimen obtained from LRM's structural size bending test.

v. Small clear specimens test were performed and the MOR, MOE and density values were recorded and are shown in Table 4.7.

Table 4.5. Ultimate local MOE, MOR and density values obtained from structural size specimens test of LRM.

Specimen number	MOE (N/mm^2)	MOR (N/mm^2)	Density (kg/m^3)
ST699-1	10066.2	44.6	601.0
ST699-2	12875.4	51.6	650.8
ST699-3	15450.5	34.1	675.1
ST699-4	15818.3	47.4	694.3
ST699-5	15450.5	49.8	689.6
ST699-6	14442.8	52.3	641.1
ST699-7	14763.8	50.2	611.4
ST699-8	15099.3	57.8	650.8
ST699-9	13287.4	47.2	719.5
ST699-10	13841.0	55.6	660.5
ST699-11	12079.5	44.9	707.1
ST699-12	14135.5	54.5	712.3
ST699-13	13026.9	57.3	687.1

ST699-14	13558.6	53.4	692.1
ST699-16	11072.8	50.6	660.6
ST699-17	14135.5	54.5	667.8
ST699-18	15099.3	61.6	688.2
ST699-19	13026.9	61.8	683.1
ST699-21	14135.5	50.9	706.9
ST699-22	13287.4	62.0	678.2
ST699-23	13841.0	57.0	698.7
ST699-24	13287.4	61.1	675.0
ST699-25	14963.3	47.8	661.2
ST700-1	11260.5	49.2	631.3
ST700-2	12303.1	54.9	681.4
ST700-3	12079.5	53.5	674.6
ST700-4	12776.3	57.3	646.8
ST700-5	13287.4	59.3	660.2
ST700-6	13287.4	47.0	673.4
ST700-7	14442.8	55.1	633.3
ST700-8	13287.4	54.9	657.5
ST700-9	12535.3	45.1	623.1
ST700-10	14287.5	47.0	679.3
ST700-11	11655.6	53.9	677.2
ST700-12	13026.9	55.2	700.5
ST700-13	12535.3	56.7	628.2
ST700-14	12535.3	54.4	634.4
ST700-15	10891.3	50.0	653.7
ST700-16	12900.4	55.9	715.1
ST700-17	9916.0	46.5	677.8
ST700-18	13986.7	58.2	694.0
ST700-19	11165.9	47.9	818.9
ST700-20	13421.6	58.7	684.0
ST700-21	13026.9	53.9	665.2
ST700-22	12079.5	45.1	688.6
ST700-23	14135.5	56.8	684.7
ST700-24	12418.1	59.6	673.9
ST700-25	13026.9	52.1	661.3
Mean	13187.8	52.8	673.6
Standard Deviations	1360.2	5.6	34.4

Therefore, the derivation of the characteristic values was based on mechanical properties obtained from structural size bending test. Later, through the formulae's, the factors that significantly affect the final values will be observed and discussed. The statistical approach is in some way similar to the basic and grade stresses analysis described in Timber Trade Leaflet No.37 which applied the formula (Engku, 1971);

$$basic\ stress = X_{mean} - 2.33SD \big/ factor\ of\ \ safety \tag{2.2}$$

However the techniques are much more complicated.

4.4.1 CHARACTERISTIC VALUE OF MODULUS OF ELASTICITY

Ultimate values of MOE obtained from structural specimens test required adjustments to derive the characteristic value of modulus of elasticity, $E_{0,mean}$. Mean value for modulus of elasticity $\overline{E}$ is calculated from the following equation, which includes an adjustment to a pure bending modulus of elasticity;

$$\overline{E} = \left[\sum E_i \Big/ n \right] 1.3 - 2690 \tag{4.17}$$

where E_i i'th value of ultimate modulus of elasticity in the range of 1 to n, in N/mm^2

Hence,

$$\overline{E} = [13187.8]1.3 - 2690$$

$$\overline{E} = 14454.1 \quad N/mm^2$$

After adjusting the value of $\overline{E}$ for each sample, the characteristic value $E_{0,mean}$ is calculated using the equation;

$$E_{0,mean} = \frac{\sum \overline{E}_j n_j}{\sum n_j} \tag{4.18}$$

where n_j number of specimen in sample j

$\overline{E}_j$ mean value of modulus of elasticity for sample j, in N/mm^2

Since there is only one sample, hence;

$$E_{0,mean} = 14454.1 \quad N/mm^2 \tag{4.19}$$

4.4.2 CHARACTERISTIC VALUE OF STRENGTH

For every sample, 5-percentile value of MOR, f_{05} was determined via a tabulated ultimate MOR values. f_{05} was obtained by sorting all the test values within a sample in ascending order. The 5-percentile value is the test value for which 5% of the values are lower or equal. This was not an actual test value (the number of test values was not divisible by 20), thus interpolation between the two adjacent values was required.

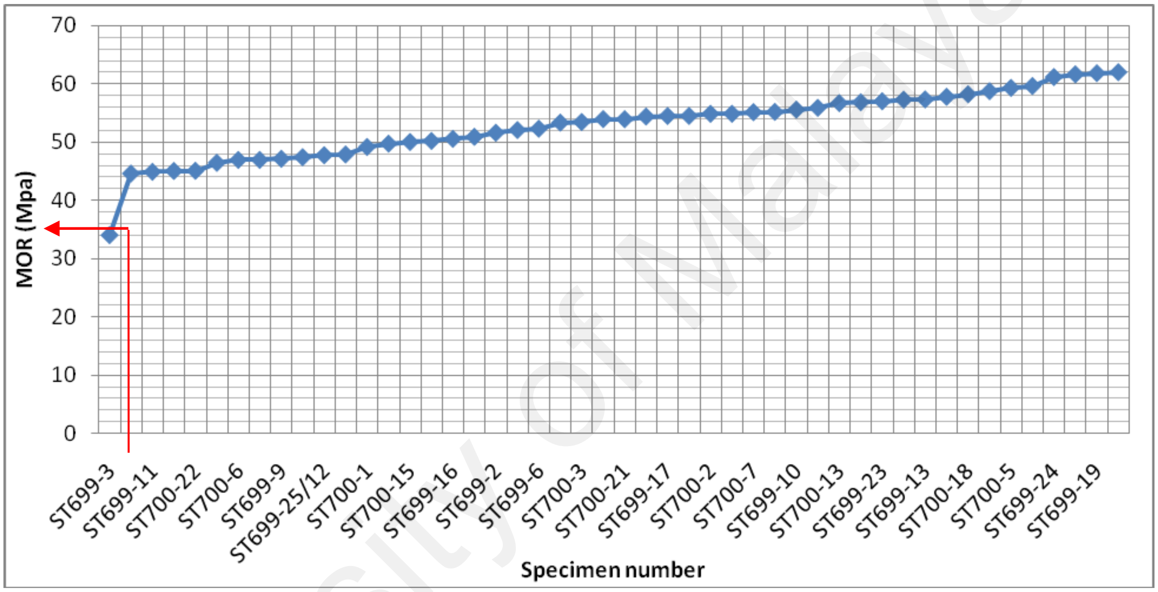


Figure 4.19. Determination of 5-percentile value of MOR.

Based on the plotted graph in Figure 4.19;

$$f_{05} = value\ \ for\ which\ 5\%\ of\ \ the\ tabulated\ values\ are\ lower\ or\ equal \qquad (4.20)$$

The minimum and maximum MOR values were 34.1 Mpa and 62.0 Mpa respectively. Hence, the 5% lower value was;

$$62.0 - 34.1 \big/ 20 = 1.4\ Mpa\ as\ of\ \ the\ \ first\ specimen$$

Thus, 5-percentile value of MOR, f_{05} is;

$$f_{05} = 35.5 \quad N/mm^2$$

The 5-percentile value of MOR, f_{05} was then derived for specimen dimension adjustment. For bending members, length effects and load configuration effects are found to be much more important than depth effects (Madsen, 1986). The reference condition corresponds to a depth of 150 mm and overall span of 18 times the specimen depth (EN 384:2004). Therefore, based on timber size and length adjustment, f_{05} was adjusted to 150 mm depth or width by dividing the value with;

$$k_h = \left(150/h\right)^{0.2} \tag{4.21}$$

(k_h , timber size adjustment factor). In this study, the specimen depth for bending test was 150 mm. Consequently;

$$k_h = 1$$

Adjustment factor based on this method somehow opposed to the basic of specimen size effect in bending test. Based on Equation 4.21, let's view the consequences in a table form:

Table 4.6. Results of timber size adjustment factor on MOR value.

Actual depth, h (mm)	$k_h = \left(150/h\right)^{0.2}$	Consequences
100	1.084	MOR will be divided with 1.084
150	1.000	MOR will be divided with 1.000
200	0.944	MOR will be divided with 0.944

Our basic knowledge regarding size effect or particularly depth effect on bending strength of timber is that the larger the specimen is the lower the MOR value will be. On the other hand, the size adjustment factor based on Equation 4.21 gives a different judgment. Table 4.6 shows that the larger the specimen is the better factor it will get. MOR value of a smaller specimen will be penalised through this factor. But of course that does not mean that MOR of a larger specimen will resulted in a higher value than the smaller one. It is simply an adjustment factor, meant to fine-tune the most exact bending strength value can be obtained from a timber specimen. Obviously the equation tells that 150 mm (6 inches) depth is the most appropriate dimension to give a true bending strength value.

Adjustment of loading point arrangement for bending test is described in EN 408:2003 (span, $\ell = 18h$; distance between inner load points, $a_f = 6h$). Therefore, the 5-percentile bending strength is adjusted for specimen length factor by dividing the value with;

$$k_l = \left(\ell_{es} / \ell_{et} \right)^{0.2} \tag{4.22}$$

$$\ell_{es} \; or \; \ell_{et} = \ell + 5a_f \tag{4.23}$$

Thus,

$$k_l = \left(18h + 5(6h) / \ell + 5a_f \right)^{0.2} \tag{4.24}$$

where	h	depth of the specimen
	ℓ	span for the conducted test
	a_f	distance between inner load points

In this study, the loading point arrangement for bending test is as described in the standard procedure. Consequently;

$$k_l = 1$$

Therefore, no modifications on the f_{05} value via specimen dimension and loading point adjustments.

$$f_{05} = 35.5 \quad N/mm^2$$

One noteworthy modification factor that affects f_{05} value is the sampling size and number of specimens. The factor is intended to reward test programmes that properly represent the variability of the population (Hugh, 2010). Therefore, sample size and number of specimens is a credit to the characteristic value of strength, f_k if the amount adequately represents the entire population of that particular timber, and vice versa. A sample is defined as a population of same timber (in this assessment it is of the same trade group), dimension, source, and is in the same production time.

The adjustment value for the effects of number of samples and their sizes is resolved using Figure 4.20 (EN 384:2004). The characteristic value of bending strength f_k shall be calculated from the equation;

$$f_k = \bar{f}_{05}\, k_s\, k_v \qquad (4.25)$$

where $\bar{f}_{05}$ mean of the adjusted f_{05} for all samples, in N/mm^2

k_s modification factor for the number of samples and their sizes referred from Figure 4.20

k_v factor for the lower variability of f_{05} values between samples for machine grades in comparison with visual grades: for all visual grades k_v = 1.0

If $\bar{f}_{05}$ is greater than the lowest adjusted sample value of f_{05} times 1.2, then either the reference population shall be redefined to eliminate the lowest value, or $\bar{f}_{05}$ shall be given the value of 1.2 times the extreme low value of f_{05}. This means;

if,

$$\bar{f}_{05} > 1.2 \times lowest\ adjusted\ \ f_{05} \tag{4.26}$$

then

$$\bar{f}_{05} = 1.2 \times lowest\ adjusted\ \ f_{05} \tag{4.27}$$

In this study, since there was only one sample, the lowest sample value of adjusted f_{05} is 35.5 N/mm^2, hence;

$$\bar{f}_{05} \leq 1.2 \times lowest\ adjusted\ \ f_{05} \tag{4.28}$$

$$\bar{f}_{05} = 35.5 \quad N/mm^2$$

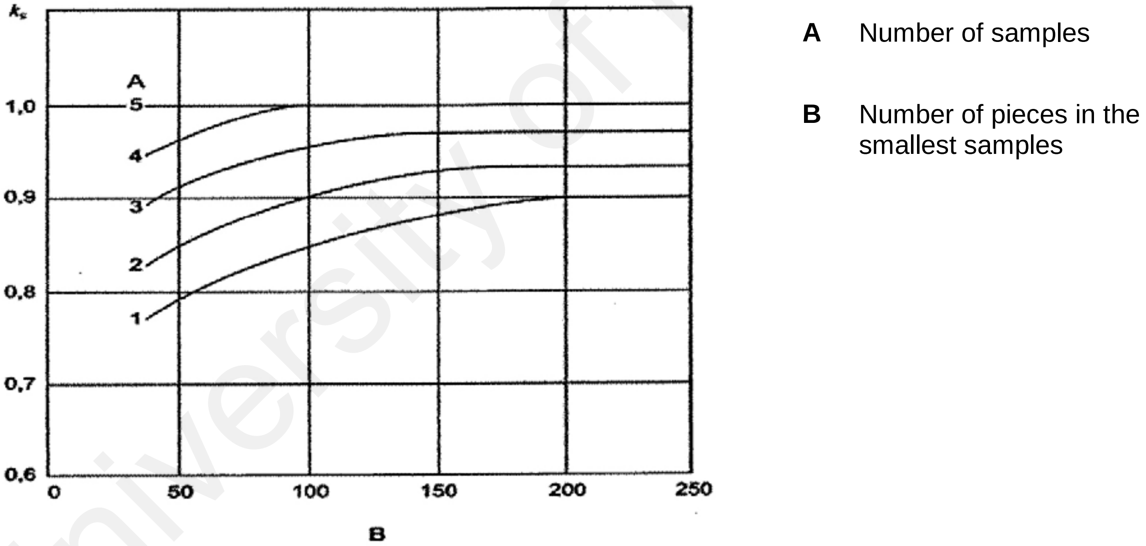


Figure 4.20. The effects of the number of samples and samples' sizes on the factor k_s (EN 384:2004).

The amount of sample concerned here is 1, meaning that only 1 sample group of the same trade group, dimension, source and time of production is considered. The sample contains

48 specimens. Consequently, based on the modification factor for effects of number of samples and sizes, characteristic value of bending strength, f_k is;

$$f_k = \bar{f}_{05}\, k_s\, k_v \tag{4.25}$$

$$f_k = 35.5 \times 0.79 \times 1 \quad N/mm^2$$

$$f_k = 28.0 \quad N/mm^2 \tag{4.29}$$

The results demonstrated that for the structural size assessment, the key effect for strength characteristic value, f_k are the number of sample and quantity of specimen. The value was being penalised from 35.5 N/mm^2 to 28.0 N/mm^2 due to the adjustment on sample and specimen size. Therefore, a large number of tests have to be done so that the results may fairly represent the average strength qualities of the timber, and the tests have to be made on specimens of timber selected from as many different trees (Thomas, 1931). Thus, specimens should be acquired from at least 5 different sources, with at least 40 specimens in a sample, to avoid the value reduction due to the sample and specimen size adjustment.

4.4.3 CHARACTERISTIC DENSITY

The 5-percentile density, ρ_k is calculated using the equation;

$$\rho_{05} = \left(\bar{\rho} - 1.65s\right) \tag{4.30}$$

Where $\bar{\rho}$ and s are sample's mean density and standard deviation respectively. Thus;

$$\rho_{05} = \left(673.6 - 1.65(34.4)\right)$$

$$\rho_{05} = 616.84 \quad kg/m^3$$

The characteristic density ρ_k is calculated using the equation;

$$\rho_k = \frac{\sum \rho_{05,j}\, n_j}{\sum n_j} \tag{4.31}$$

where $\rho_{05,j}$ 5-percentile value of density for sample j, in kg/m^3

n_j number of specimens in sample j

Since there is only one sample in consideration, thus:

$$\rho_k = \frac{\sum \rho_{05,j}\, n_j}{\sum n_j} \tag{4.31}$$

$$\rho_k = 616.84 \quad kg/m^3 \tag{4.32}$$

4.5 EN STRENGTH CLASS FOR LRM

Based on the characteristic value of strength, f_k characteristic value of MOE, $E_{0,mean}$, and characteristic density, ρ_k, EN strength class for LRM can be determined by referring to Appendix 1. Having

$$f_k = 28.0\ N/mm^2 \tag{4.29}$$

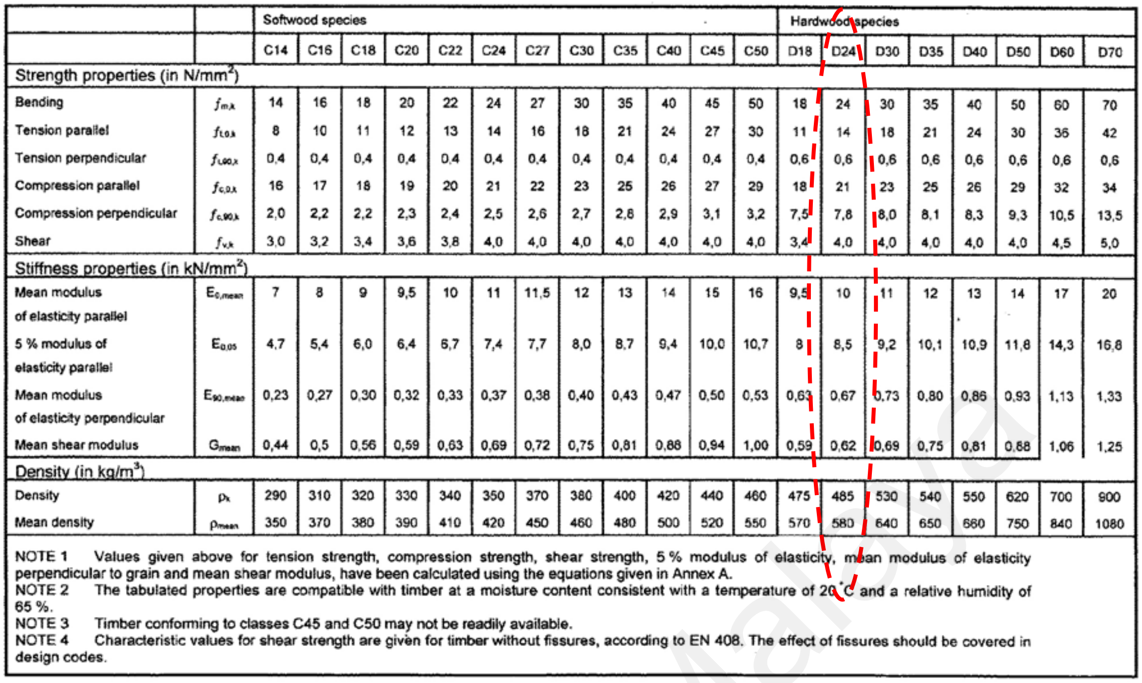
LRM suit to be in strength class D24. Calculated values of

$$E_{0,mean} = 14454.1\ N/mm^2 \tag{4.19}$$

and

$$\rho_k = 616.84\ kg/m^3 \tag{4.32}$$

further qualified LRM to be in D24 where the minimum requirements of $E_{0,mean}$ and ρ_k are 10,000 N/mm^2 and 485 kg/m^3 respectively.



		Softwood species												Hardwood species							
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D18	D24	D30	D35	D40	D50	D60	D70
Strength properties (in N/mm^2)																					
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	18	24	30	35	40	50	60	70
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	11	14	18	21	24	30	36	42
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29	18	21	23	25	26	29	32	34
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	7,5	7,8	8,0	8,1	8,3	9,3	10,5	13,5
Shear	$f_{v,k}$	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0	4,0	3,4	4,0	4,0	4,0	4,0	4,0	4,5	5,0
Stiffness properties (in kN/mm^2)																					
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	9,5	10	11	12	13	14	17	20
5 % modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8	8,5	9,2	10,1	10,9	11,8	14,3	16,8
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,63	0,67	0,73	0,80	0,86	0,93	1,13	1,33
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,59	0,62	0,69	0,75	0,81	0,88	1,06	1,25
Density (in kg/m^3)																					
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	475	485	530	540	550	620	700	900
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550	570	580	640	650	660	750	840	1080

NOTE 1 Values given above for tension strength, compression strength, shear strength, 5 % modulus of elasticity, mean modulus of elasticity perpendicular to grain and mean shear modulus, have been calculated using the equations given in Annex A.

NOTE 2 The tabulated properties are compatible with timber at a moisture content consistent with a temperature of 20 °C and a relative humidity of 65 %.

NOTE 3 Timber conforming to classes C45 and C50 may not be readily available.

NOTE 4 Characteristic values for shear strength are given for timber without fissures, according to EN 408. The effect of fissures should be covered in design codes.

Figure 4.21. Strength class for LRM (EN 338:2009).

4.6 MEAN VALUES OF SMALL CLEAR SPECIMENS OF LRM

Based on the formula of three-point bending, the MOE and MOR for each specimen were calculated and recorded in Table 4.7. Mean modulus of elasticity of small clear specimens of LRM, $\bar{E}_{small}$ is;

$$\bar{E}_{small} = {E_{small}}/{n} \tag{4.33}$$

$$\bar{E}_{small} = 8893.8 \quad N/mm^2 \tag{4.34}$$

Mean modulus of rupture of small clear specimens, $\bar{f}_{small}$

$$\bar{f}_{small} = {f_{small}}/{n} \tag{4.35}$$

$$\bar{f}_{small} = 68.5 \quad N/mm^2 \tag{4.36}$$

Mean density of small clear specimens, $\bar{\rho}_{small}$

$$\overline{\rho}_{small} = {}^{\rho_{small}}\!\!\diagup_{n} \qquad (4.37)$$

$$\overline{\rho}_{small} = 671.2 \quad kg/m^3 \qquad (4.38)$$

Table 4.7. MOE, MOR and density values obtained from small clear specimens test of LRM.

Specimen number	MOE (Mpa)	MOR (Mpa)	Density (kg/m3)
ST699/14-1/09/11	8073.5	63.1	685.9
ST699/14-2/09/11	8881.3	69.2	630.9
ST699/14-3/09/11	8820.3	69.3	757.8
ST699/15-1/09/11	10139.6	74.4	673.3
ST699/15-2/09/11	9219.6	65.4	691.7
ST699/15-3/09/11	9119.5	69.4	659.0
ST699/16-1/09/11	8818.6	72.0	670.7
ST699/16-2/09/11	10035.5	79.1	635.2
ST699/16-3/09/11	8750.2	73.2	667.6
ST699/17-1/09/11	9577.6	73.7	683.7
ST699/17-2/09/11	9174.2	78.3	683.9
ST699/17-3/09/11	8942.7	70.2	651.8
ST699/18-1/09/11	8895.6	70.5	655.9
ST699/18-2/09/11	9664.3	78.6	665.8
ST699/18-3/09/11	9086.9	74.1	664.0
ST699/19-1/09/11	10054.4	76.0	684.3
ST699/19-2/09/11	9350.3	66.2	663.3
ST699/19-3/09/11	9585.3	73.4	651.1
ST699/20-1/09/11	10229.0	74.9	631.1
ST699/20-2/09/11	10380.6	74.6	652.4
ST699/20-3/09/11	10486.7	75.0	643.6
ST699/21-1/09/11	9394.8	75.0	654.6
ST699/21-2/09/11	8998.9	65.2	744.0
ST699/21-3/09/11	9057.1	65.1	721.4
ST699/22-1/09/11	9418.2	78.8	644.5
ST699/22-2/09/11	9361.3	74.5	641.6
ST699/22-3/09/11	8929.4	77.4	636.0
ST699/23-1/09/11	9253.2	74.2	641.2
ST699/23-2/09/11	8638.2	69.1	614.7
ST699/23-3/09/11	9238.5	70.6	642.4
ST699/24-1/09/11	9593.5	74.9	651.2
ST699/24-2/09/11	8974.0	72.0	648.9
ST699/24-3/09/11	9243.2	71.8	652.9
ST700/1-1/09/11	9214.4	69.5	665.3
ST700/1-2/09/11	9264.0	70.6	662.6
ST700/1-3/09/11	9164.4	71.0	677.3
ST700/2-1/09/11	9333.9	75.9	694.5
ST700/2-2/09/11	8392.6	66.9	680.7
ST700/2-3/09/11	8820.4	68.8	691.1

ST700/3-1/09/11	9495.1	67.1	665.2
ST700/3-2/09/11	9579.9	71.1	673.7
ST700/3-3/09/11	10004.5	71.2	670.0
ST700/4-1/09/11	9551.5	71.7	661.3
ST700/4-2/09/11	9172.7	69.2	660.3
ST700/4-3/09/11	8360.4	69.3	636.6
ST700/5-1/09/11	9751.9	68.4	663.9
ST700/5-2/09/11	9643.3	71.8	706.8
ST700/5-3/09/11	9794.9	72.0	648.0
ST700/6-1/09/11	8549.1	61.4	698.4
ST700/6-2/09/11	10703.1	73.6	644.9
ST700/6-3/09/11	8520.3	68.3	718.7
ST700/7-1/09/11	8905.6	72.2	617.8
ST700/7-2/09/11	8503.6	68.4	626.8
ST700/7-3/09/11	8656.7	70.8	655.2
ST700/8-1/09/11	9429.1	63.7	724.6
ST700/8-2/09/11	9047.4	63.7	745.3
ST700/8-3/09/11	8342.5	62.4	633.9
ST700/9-1/09/11	6785.9	49.2	618.8
ST700/10-1/09/11	8556.6	67.0	720.2
ST700/10-2/09/11	9160.4	69.6	756.2
ST700/10-3/09/11	9222.2	62.7	648.1
ST700/11-1/09/11	8437.1	68.5	444.1
ST700/11-2/09/11	7443.5	63.6	607.8
ST700/11-3/09/11	8258.8	69.8	731.3
ST700/12-1/09/11	7709.4	58.1	686.0
ST700/12-2/09/11	8438.0	61.8	718.2
ST700/12-3/09/11	9340.3	67.4	689.0
ST700/13-1/09/11	7906.1	64.3	685.7
ST700/13-2/09/11	8142.6	65.4	712.7
ST700/13-3/09/11	8225.6	66.3	677.9
ST700/14-1/09/11	8890.5	64.9	647.5
ST700/14-2/09/11	9027.3	70.4	640.2
ST700/15-1/09/11	9180.0	66.4	668.0
ST700/15-2/09/11	8724.0	62.3	666.2
ST700/15-3/09/11	8912.2	58.7	693.2
ST700/16-1/09/11	9026.7	67.7	714.5
ST700/16-2/09/11	8136.7	66.5	692.9
ST700/16-3/09/11	8391.9	67.5	693.3
ST700/18-1/09/11	8304.7	68.1	667.2
ST700/18-2/09/11	9113.6	66.0	647.1
ST700/18-3/09/11	7838.4	66.9	668.2
ST700/19-1/09/11	8904.0	60.6	677.1
ST700/19-2/09/11	8721.3	55.8	704.1
ST700/19-3/09/11	8124.7	54.8	686.0
ST700/20-1/09/11	9148.3	68.2	688.1
ST700/20-2/09/11	9279.2	72.1	683.7
ST700/20-3/09/11	8165.6	64.8	683.7
ST700/21-1/09/11	8184.3	69.6	641.9
ST700/21-2/09/11	7773.2	64.1	630.8
ST700/22-1/09/11	7931.2	68.6	634.6
ST700/22-2/09/11	7634.3	65.8	727.2
ST700/22-3/09/11	8243.8	62.3	698.1
ST700/23-1/09/11	8195.3	63.4	699.6
ST700/23-2/09/11	8013.4	66.2	733.3
ST700/23-3/09/11	7995.9	64.6	697.1

ST700/24-1/09/11	8812.6	68.3	663.2
ST700/24-2/09/11	7935.1	68.8	708.9
ST700/24-3/09/11	7300.8	57.9	649.3
ST700/25-1/09/11	9134.9	73.0	629.4
ST700/25-2/09/11	8973.2	71.9	743.6
ST700/25-3/09/11	9046.8	68.4	695.2
Mean	8893.8	68.5	671.2
Standard Deviations	711.8	5.4	40.3

4.7 MEAN VALUES FROM EXISTING SMALL CLEAR DATA

Mean MOR, MOE and density values of small clear specimens are listed in Timber Trade Leaflet No.34 (Lee et al., 1993). However, only a single mean value for each trade group is required for the comparison with full size data. Furthermore, the assessment was limited to data obtained from at least 40 specimens and from at least 5 trees (Hugh, 2010) in a single trade group (please refer to Appendix 2). Hence, a weighted average calculation is required to obtain a single MOR and MOE value from each group.

Weighted mean MOE, $\overline{E}_{small,w}$ is calculated using the equation:

$$\overline{E}_{small,w} = \frac{\sum \overline{E}_{small,j}\, n_j}{\sum n_j} \tag{4.39}$$

Weighted mean MOR, $\bar{f}_{small,w}$ is calculated using the equation:

$$\bar{f}_{small,w} = \frac{\sum \bar{f}_{small,j}\, n_j}{\sum n_j} \tag{4.40}$$

where $\overline{E}_{small,j}$ mean MOE for sample j, in N/mm^2

$\bar{f}_{small,j}$ mean MOR for sample j, in N/mm^2

n_j number of specimens for sample j

The results of the weighted mean values calculation in table form as shown in Table 4.8.

Table 4.8. Weighted mean values of the existing small clear data.

Trade group	Total number of trees	Total number of specimen for bending test @ 15% MC	Weighted mean MOR (MPa)	Weighted mean MOE (MPa)	Density @ 15% MC (kg/m^3)
Bitis	5	39	171.0	23800	1120
Cengal	5	51	149.0	19600	945
Balau	5	60	142.0	20100	960
Kekatong	5	49	135.0	18400	1010
Kempas	5	41	122.0	18600	850
Tualang	5	64	121.0	17800	880
Merbatu	5	70	119.0	19700	895
Merbau	5	42	116.0	15400	800
Kapur	5	55	114.0	18700	800
Nyatoh	10	50	113.0	16348	905
Merpauh	11	98	102.2	16686	740
Meranti, White	20	127	101.2	14808	703
Keledang	6	46	100.9	14065	677
Balau, Red	9	79	99.61	15663	755
Keruing	16	187	98.34	17645	792
Ramin	5	84	88.00	15900	675
Meranti, Dark Red	11	93	82.72	12845	610
Mempisang	10	39	81.15	13923	675
Kedondong	5	52	81.00	12177	617
Durian	7	55	77.87	12271	580
Bintangor	5	58	74.00	14300	575
Meranti, Light Red	13	91	71.00	12257	557
Terentang	5	64	42.00	7000	370

4.8 CONVERSION FACTORS OF LRM AND SIMILAR GROUP TIMBERS

The relationship of structural size and small clear specimens of LRM timber through linear correlation can be abridged as below;

$$MOR_{structural} = 0.64\, MOR_{small\ clear} + 11.30 \tag{4.4}$$

$$MOE_{structural} = 0.80\, MOE_{small\ clear} + 6175.10 \tag{4.5}$$

The derivations of conversion factors via characteristic values are achievable when both structural test data and existing small clear records are available. These factors are derived from ratios of the characteristic values from the structural size data over the mean values of the existing small clear data. Based on test results of LRM timber, therefore;

i. Conversion factor for MOR (Equation 4.29 and 4.36);

$$f_k = 28.0\ N/mm^2$$

$$\bar{f}_{small} = 68.5 \quad N/mm^2$$

Therefore;

$$f_k = 0.41\, \bar{f}_{small} \tag{4.41}$$

ii. Conversion factor for MOE (Equation 4.19 and 4.34);

$$E_{0,mean} = 14454.1 \quad N/mm^2$$

$$\bar{E}_{small} = 8893.8 \quad N/mm^2$$

Therefore;

$$E_{0,mean} = 1.63\, \bar{E}_{small} \tag{4.42}$$

iii. Conversion factor for density (Equation 4.32 and 4.38);

$\rho_k = 616.84 \quad kg/m^3$

$\overline{\rho}_{small} = 671.2 \quad kg/m^3$

Therefore;

$$\rho_k = 0.92\ \overline{\rho}_{small} \tag{4.43}$$

These factors are then permitted to be applied to similar trade group timbers where only small clear data exist, provided that the number of specimens in a sample shall be at least 40, obtained from at least five trees, and the test methods shall be the same in all cases. Characteristic values determined in this approach shall be reduced by multiplying with 0.9 (Lanvin, 2009).

$$E_{0,mean} \times 0.9 \tag{4.44}$$

$$f_k \times 0.9 \tag{4.45}$$

$$\rho_k \times 0.9 \tag{4.46}$$

Therefore, conversion factors derived from LRM are applicable to other timber groups in E5 (Table 4.4). The calculated values shall then be reduces by 10% and set into equivalent European strength classes (Appendix 1). Priority has to be arranged from bending strength, followed by modulus of elasticity and density sequentially.

4.9 CONCLUDING REMARKS

The results of structural size tests of some selected Malaysian hardwoods have been discussed in the beginning of this chapter. In general, the MOE and MOR results have shown significant differences when compared to the small clear test method. Next, a statistical technique for grouping timber into similar strength classification has been presented. This technique is meant to assist in the conversion assessment since the correlation factors only applicable to species with similar strength characteristics. Lastly, the formulation of the correlation factor based on testing results of LRM timber was discussed.

CHAPTER 5

CONCLUSIONS

i. In general, the results indicated that MOR of structural size specimens are lower compared to small clear. On the other hand, the structural size MOE were found higher compared to the small clear. These results are consistent with reports by Newlin (1930), Madsen and Buchanan (1986) and Alik and Badorul Hisham (2006). The MOE relationship between structural and small clear specimens was shown to be more consistent compared to MOR. Analysis showed that linear correlation is most appropriate between the two testing methods. To build the degree of confidence in the linearity of the two methods, a sort-plot technique was demonstrated. Through linear regression plots, structural and small clear specimens are correlated with;

$$MOR_{structural} = 0.64\, MOR_{small\ clear} + 11.30 \qquad (4.4)$$

$$MOE_{structural} = 0.80\, MOE_{small\ clear} + 6175.10 \qquad (4.5)$$

The local and global values showed a smooth linear correlation with regression value of $R^2 = 0.84$. Good correlation justified the consistency and reliability of the two measurements. Consistent results were also obtained by Simon et al. (2002) and Bostrom (1999). However, the method is very sensitive to measurement errors. Twist, cup or warp specimen resulted in buckling during test and lead to erroneous MOR and MOE values.

ii. Timber selection for deriving the conversion factors is very crucial. First and foremost, it must be an abundant species with high global market demand. It is meaningless to established strength data for depleting timber species, which very hard to obtain even if the demand is high. The next rationale is that the selected timber will automatically be incorporated in the appropriate structural strength class. Furthermore, the properly selected timber is essential to represent the population of the so-called ‘similar species’. Weighted average calculation with Student’s T test was demonstrated to be a suitable method for the classification of Malaysian timbers into similar groups. Six strength groups, namely E1 to E6, were introduced based on the MOE values of the existing small clear specimen archive. The timber strength arrangement through t-test analysis indicates that the outcome is almost similar to the grouping by Burgess (1956), Engku (1972) and Chu et al. (1997). The classification is very important to determine the scope on which the conversion factors will be applied.

iii. An alternative method of determining characteristic values of structural timber was demonstrated through modification of small clear specimen data. The objective of the present work is to provide a general correlation factors between structural size and small clear specimens of timber using the results of Light Red Meranti bending test. The conversion factors are summarised in Table 5.1.

Table 5.1. Conversion factors developed from LRM structural test results.

	Characteristic values of structural size specimens	Mean values of small clear specimens	Conversion Ratio
Bending Strength (N/mm^2)	28.0	68.5	$f_k = 0.41\ \bar{f}_{small}$ (4.41)
Modulus of Elasticity (N/mm^2)	14454.1	8893.8	$E_{0,mean} = 1.63\ \bar{E}_{small}$ (4.42)
Density (kg/m^3)	616.8	671.2	$\rho_k = 0.92\ \bar{\rho}_{small}$ (4.43)

Knowledge and skill of timber grading is unavoidable in this assessment. The main reason is to avoid improper specimen being included in the test results. Technically, the dimension adjustment will deduct some values from the 5-percentile bending strength. It is demonstrated in Figure 4.20 that a radically low MOR value will pin down the 5-percentile value measurement. Although the penalty is not as greatly as the sample size adjustment, a premeditated defect-specimen through good grading practice will aid the 5-percentile value reduction. The number of weak specimen that fulfills the requirements for visual grading will affects that determination of the characteristic strength value.

It is observed in the structural size assessment, how vital the effect of the number of sample and quantity of specimen on MOR characteristic value, f_k. The value was being penalized from 35.5 N/mm^2 to 28.0 N/mm^2 due to the sample and specimen size adjustment. Thus, specimens should be acquired from at least 5 different sources, with at least 40 specimens in a sample, to avoid the value reduction due to the sample and specimen size adjustment.

The best specimen's depth to obtain a representative MOR value in structural size test is 150 millimeters or 6 inches. The bending strength will be penalised with an adjustment factor if the depth of the specimen is less than 150 mm. In contrast, some credit values will be added to the bending strength if the depth of the specimen more than 150 mm. However, the testing will be more complicated for specimen with higher depth due to high tendency to buckle.

The structural strength assessment of Malaysian timber is by no means completed. In reality, the conclusion of this present study is just foundation for more extensive works in structural size testing of Malaysian timbers.

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