POSSIBILITY OF PREDICTING MECHANICAL STRENGTH PROPERTIES OF MALAYSIAN TIMBERS

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Ong, S. H. 1988. Possibility of predicting mechanical strength properties of Malaysian timbers. Regression equations for predicting the mechanical strength properties from wood density and moisture content of Malaysian timbers are given in this paper. The high R^2 values show that regression equations are reliable for small clear samples.

Key words: Malaysian timbers - strength properties - wood density - moisture content - regression equations

Introduction

The strength properties of timber are important in determining the end uses. As such, accurate prediction of timber properties benefit both the manufacturer and consumer.

Usually, there is no way of knowing the strength of a particular timber without breaking it; non destructive means of evaluating the strength of timber is difficult. Largely due to this, only some well known timber species have been selected for some end uses. That even these well known species vary greatly in wood properties is frequently ignored.

The main objective of this study was to investigate the correlation of wood density and moisture content with strength properties, so that, that of small clear samples can be predicted by using regression equations. Other objectives of the study were to determine the relationships between the strength properties, and whether these relationships can be used for predicting mechanical strength properties by knowing another strength property.

Methods

Timber properties used in this study were based on those obtained from laboratory testing of small specimens (Lee *et al.* 1979). Data in each observation are species means; species and the number of tests to determine the species means are given in Appendix 1. The results are based on the 50.8 *mm* standard size.

The methods of testing have been described by Flemmich (1959). They are similar to those standardised by the British Standards Institution (B. S. 373 : 1957) for 50.8 *mm* specimens and the American Society for Testing Materials (ASTM Designation : D143-52).

Factors for adjusting mechanical property data between 50.8 x 50.8 *mm* and 20 x 20 *mm* standards, given by Lavers 1969 are as follows:

Ratio of strength means 50.8 *mm*/20 *mm*

Modulus of rupture (MOR)	Modulus of elasticity (MOE)	Work to maximum load	Total work	Maximum drop strength parallel to grain	Maximum compression	Shear	Cleavage
$N\ mm^{-2}$	$N\ mm^{-2}$	$mm\ N\ mm^{-3}$	$mm\ N\ mm^{-3}$	m	$N\ mm^{-2}$	$N\ mm^{-2}$	$N\ m^{-1}$ width
0.95	1.07	0.82	0.79	1.00	0.96	0.88	4.35

(Abbreviations used above and elsewhere in the article refer:

BD ($g\ cm^{-3}$)	- Basic density: based on oven-dried weight and green volume;
D ($g\ cm^{-3}$)	- Estimatd wood density based on weight and volume at 15% mc;
MC (%)	- Moisture content %: based on weight of wood when dry;
MOR ($N\ mm^{-2}$)	- Modulus of Rupture: maximum bending strength;
MOE ($N\ mm^{-2}$)	- Modulus of Elasticity: stiffness;
IMPT (M)	- Impact bending: Height of drop of 22.7 *kg* hammer causing complete failure;
CPARA ($N\ mm^{-2}$)	- Compression parallel to grain, maximum crushing strength;
CPERP ($N\ mm^{-2}$)	- Compression perpendicular to grain: stress at limit of proportionality;
HARD (N)	- Side hardness: load to imbed at 11.28 *mm*diameter steel sphere to one half of its diameter;
SHEAR ($N\ mm^{-2}$)	- Shear parallel to grain: maximum shearing strength;
CRAD ($N\ mm^{-2}$ width)	- Cleavage resistance to splitting in radial plane;
CTAN ($N\ mm^{-2}$ width)	- Cleavage resistance to splitting in tangential plane.)

Results

The mean, minimum, maximum, standard error of mean and coefficient of variation in green and air-dry condition of wood density and mechanical strength properties are given in Table 1.

Correlation coefficients between variables under green and air-dry conditions are given in Tables 2 and 3.

Linear, multiple linear and quadratic regression analyses were used to study the various moisture contents and densities to predict strength properties. In general, above the fibre saturation point the effect of moisture content on strength is negligible.

Table 1. Mean, minimum, maximum, standard error of mean and coefficient of variation of wood density and mechanical strength under green and air dry conditions (13.6 - 20.6 MC%)

Variable	Number of observations	Mean	Minimum	Maximum	Standard Error of Mean	Coefficient of variation (%)
MC%	118	16.8	13.6	20.6	0.120	8
D	117	0.708	0.305	1.120	16.90	26
BD	176	0.569	0.27	0.97	0.011	26
MOR	155 (110)	69.4 (89.6)	19 (28)	156 (171)	1.940 (2.79)	35 (33)
MOE	155 (110)	12434 (13791)	3400 (3700)	22100 (23800)	312.2 (414.9)	31 (32)
IMPT	172 (118)	721 (822)	100 (180)	1600 (1730)	19.4 (28.66)	35 (38)
CPARA	176 (118)	36.7 (822)	11.7 (180)	88.7 (1730)	1.031 (28.66)	37 (31)
CPERP	145 (89)	4.91 (6.32)	0.99 (1.37)	19.72 (16.07)	0.24 (0.335)	59 (50)
HARD	176 (118)	4739 (5628)	710 (1070)	16640 (14860)	199.1 (279.6)	56 (54)
SHEAR	175 (118)	8.86 (10.8)	2.9 (3.2)	17.0 (19.3)	0.201 (0.295)	30 (30)
CRAD	151 (106)	54.2 (49.8)	12 (18)	125 (86)	1.330 (1.398)	30 (29)
CTAN	151 (106)	64.3 (57.9)	11 (16)	150 (98)	1.815 (1.577)	35 (28)

Figures in parentheses are for air dry condition

The regression equations for predicting change in mechanical strength properties due to change in wood density for small clear samples under green condition are given in Table 4 and Figure 1.

As the moisture content falls below the fibre saturation point the strength of wood increases as it dries. Regression equations for predicting the change in mechanical strength properties due to change in moisture content and wood density for small clear samples under air-dry condition (13.6-20.6 MC%) are given in Table 5 and Figure 1.

For each strength property, to achieve a better understanding of the response to several independent variables likely to be relevant and also to assess the possibilities for accurate prediction, regression equations (S. H. Ong unpublished) were used to determine the relationship between dependent and independent variables. The goodness of fit of alternative models may be compared by means of the R^2 statistic which is a measure of the proportion of variation in the dependent variable explained by the regression. Linear regressions were found to give sufficiently high R^2 values, and so other regressions were not tested.

Table 2. Correlation coefficients between some variables in green condition (Number of observations in brackets)

	BD	MOR	MOE	IMPT	CPARA	CPERP	HARD	SHEAR	CRAD	CTAN
BD	1.000 (176)									
MOR	0.918 (155)	1.000 (155)								
MOE	0.879 (155)	0.906 (155)	1.000 (155)							
IMPT	0.789 (172)	0.817 (152)	0.635 (152)	1.000 (172)						
CPARA	0.912 (176)	0.984 (155)	0.903 (155)	0.807 (172)	1.000 (176)					
CPERP	0.850 (145)	0.862 (125)	0.693 (125)	0.787 (142)	0.860 (145)	1.000 (145)				
HARD	0.919 (176)	0.913 (155)	0.755 (155)	0.866 (172)	0.913 (176)	0.919 (145)	1.000 (176)			
SHEAR	0.845 (176)	0.826 (154)	0.643 (154)	0.802 (172)	0.797 (175)	0.842 (145)	0.875 (175)	1.000 (175)		
CRAD	0.751 (151)	0.767 (150)	0.599 (150)	0.765 (149)	0.709 (151)	0.712 (122)	0.788 (151)	0.835 (151)	1.000 (151)	
CTAN	0.770 (151)	0.763 (150)	0.628 (150)	0.709 (149)	0.719 (151)	0.752 (122)	0.807 (151)	0.796 (151)	0.922 (151)	1.000 (151)

Note: Range of basic density (BD) = 0.27 - 0.97 $g\ cm^{-3}$
All correlation coefficients are statistically significant at a probability of p = 0.99

Table 3. Correlation coefficients between some variables in air-dry condition (13.6 - 20.6 MC%) (Number of observation in brackets)

	MC%	D	MOR	MOE	IMPT	CPARA	CPERP	HARD	SHEAR	CRAD	CTAN
MC%	1.000 (118)										
D	-0.050 (117)	1.000 (117)									
MOR	-0.167 (110)	0.939 (109)	1.000 (110)								
MOE	-0.101 (110)	0.890 (109)	0.931 (110)	1.000 (110)							
IMPT	-0.094 (118)	0.905 (117)	0.889 (110)	0.791 (110)	1.000 (118)						
CPARA	-0.223 (118)	0.933 (117)	0.985 (110)	0.940 (110)	0.880 (118)	1.000 (118)					
CPERP	-0.065 (89)	0.814 (89)	0.754 (81)	0.609 (81)	0.781 (89)	0.773 (89)	1.000 (89)				
HARD	-0.075 (118)	0.938 (117)	0.899 (110)	0.782 (110)	0.917 (118)	0.894 (118)	0.863 (89)	1.000 (118)			
SHEAR	-0.025 (106)	0.868 (117)	0.831 (110)	0.720 (110)	0.855 (118)	0.815 (106)	0.788 (89)	0.883 (118)	1.000 (118)		
CRAD	-0.056 (106)	0.667 (105)	0.629 (105)	0.556 (105)	0.701 (106)	0.599 (106)	0.557 (78)	0.610 (106)	0.689 (106)	1.000 (106)	
CTAN	-0.014 (106)	0.676 (105)	0.610 (105)	0.554 (105)	0.648 (106)	0.580 (106)	0.479 (78)	0.591 (106)	0.706 (106)	0.855 (106)	1.000 (106)

Note: Range of MC% at test (air-dry) = 13.6 - 20.6
Range of wood density estimated at 15% MC = 0.305 - 1.12 $g\ cm^3$
Except for MC%, all correlation coefficients are statistically significant at a probability of p = 0.99

Table 4. Regression equations for predicting the strength properties of small clear sample by basic density under green and air dry conditions

Regression			Number of observations	Coefficient of determination
MOR	=	-15 + 148.65BD	155	0.84
MOR	=	8 + 64.97BD + 71.21BD^2	155	0.85
MOE	=	-559.4 + 22891.5BD	155	0.77
MOE	=	-2443.5 + 29751.4BD - 5837.3BD^2	155	0.77
IMPT	=	-39.5 + 1334.7BD	172	0.62
IMPT	=	288 + 138.5BD + 1019.9BD^2	172	0.63
CPARA	=	-10.59 + 83.2BD	176	0.83
CPARA	=	10.6 + 5.85BD + 65.99BD^2	176	0.85
CPERP	=	-4.449 + 16.35BD	145	0.72
CPERP	=	4.805 - 17.34BD + 28.64BD^2	145	0.80
HARD	=	-4474.6 - 16206.4BD	176	0.84
HARD	=	2643.1 - 9786.2BD + 22167.8BD^2	176	0.90
SHEAR	=	0.306 + 15.02BD	175	0.71
SHEAR	=	1.176 + 11.84BD + 71BD^2	175	0.71
CRAD	=	7.43 + 82BD	151	0.56
CRAD	=	-5.67 + 129.5BD - 40.3BD^2	151	0.57
CTAN	=	-1.14 + 114.8BD	151	0.59
CTAN	=	3.12 + 99.3BD + 13.1BD^2	151	0.59

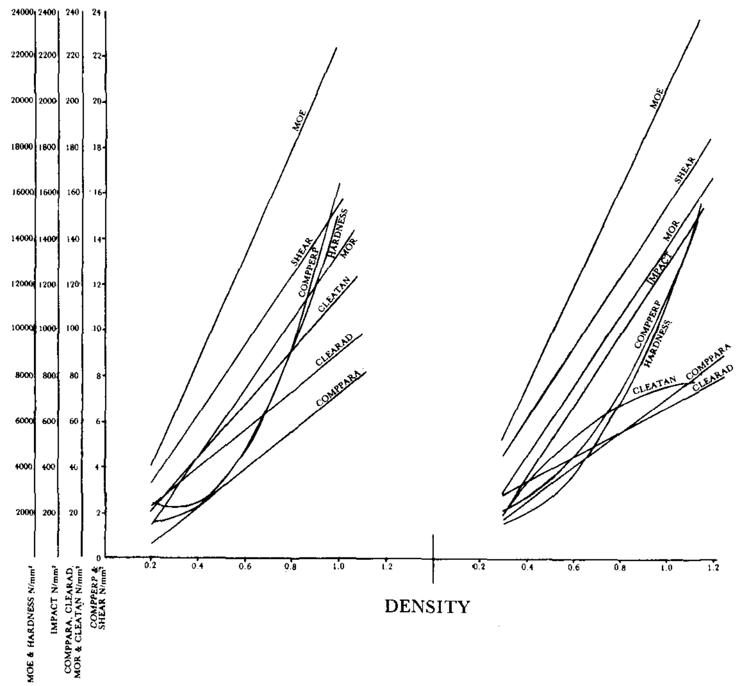

Figure 1. Effect of change of wood density under green and air dry (15 MC%) conditions on strength properties

Table 5. Regression equations for predicting the strength properties of small clear samples by moisture content and wood density under air-dry condition

Regression			Number of observations	Coefficient of determination
MOR	=	-17 + 152.6D	109	0.88
MOR	=	-0.63 + 103.6D + 34.4D^2	109	0.88
MOR	=	38.61 - 3.289MC% + 152.1D	109	0.90
MOR	=	48.87 - 3.208MC% + 117.3D + 24.5D^2	109	0.90
MOE	=	-1240 + 21509.5D	109	0.79
MOE	=	-2036 + 23890.4D - 1673D^2	109	0.79
MOE	=	3490.8 - 279.8MC% + 21464.9D	109	0.80
MOE	=	2412.1 - 288.25MC% + 25121.4D - 2570D^2	109	0.80
IMPT	=	-272.3 + 1547.4D	117	0.82
IMPT	=	-18.1 + 795D + 522.7D^2	117	0.82
IMPT	=	-89.1 - 10.79MC% + 1543.7D	117	0.82
IMPT	=	122.8 - 9.13MC% + 833.7D + 493.6D^2	117	0.83
CPARA	=	-5.42 + 75.69D	117	0.87
CPARA	=	-1.61 + 64.41D + 7.84D^2	117	0.87
CPARA	=	29.04 - 2.03MC% + 74.98D	117	0.90
CPARA	=	29.64 - 2.03MC% + 72.98D + 1.39D^2	117	0.90
CPERP	=	-4.046 + 14.43D	89	0.66
CPERP	=	2.476 - 5.05D + 13.64D^2	89	0.69
CPERP	=	-2.947 - 0.0654MC% + 14.4D	89	0.66
CPERP	=	2.739 - 0.0174MC% - 4.97D + 13.58D^2	89	0.69
HARD	=	-5407.8 + 15621.3D	117	0.88
HARD	=	2361.8 - 7382.4D + 15980D^2	117	0.93
HARD	=	-4612.2 - 46.85MC% + 15605D	117	0.88
HARD	=	2258.4 + 6.7MC% - 7410.7D + 16000D^2	117	0.93
SHEAR	=	-0.05 + 15.31D	117	0.75
SHEAR	=	-0.5 + 16.61D - 0.91D^2	117	0.75
SHEAR	=	-0.78 + 0.043MC% + 15.32D	117	0.75
SHEAR	=	-1.11 + 0.04MC% + 16.44D -0.78D^2	117	0.75
CRAD	=	11.8 + 54.4D	105	0.45
CRAD	=	-12.03 + 125.4D - 49.8D^2	105	0.46
CRAD	=	19.57 - 0.458MC% + 54.3D	105	0.45
CRAD	=	-2.74 - 0.596MC% + 127.7D - 51.5D^2	105	0.47
CTAN	=	14.48 + 62.16D	105	0.46
CTAN	=	-30.07 + 194.96D - 933.15D^2	105	0.51
CTAN	=	7.3 + 423MC% + 62.25D	105	0.46
CTAN	=	-32.82 + 0.176MC% + 194.28D - 92.65D^2	105	0.51

Discussion and conclusion

The proportion of the variation explained by regression equations, as indicated by the value of R^2, were mostly higher than 0.70 for small clear specimens at green and air-dry conditions. Except for cleavage strength (R^2 < 0.60), those models in practical terms can be used to predict strength properties reliably by measuring wood density and moisture content (Tables 4 & 5).

For models involving wood density, the values of R^2 were higher than those containing moisture content or single independent variable of strength properties value only. Slightly higher R^2 values resulted when three variable models containing wood density, moisture content and a single independent variable of strength properties were used (Tables 4 & 5). This shows that wood density is the best indicator of strength properties. No improvement or only slightly improved R^2 values resulted when quadratic regressions were used (Tables 4 & 5). It may be assumed that the strength properties are directly proportional to wood density when the moisture content is constant.

Regression equations for predicting values of mechanical strength properties from small clear specimens must be used with caution. The range of basic density of green sample was 0.27 - 0.97 $g\ cm^{-3}$, the range of moisture content of air-dry specimen 13.6 - 20.6%, and that of wood density at 15% MC 0.305 - 1.12 $g\ cm^{-3}$. For wood samples beyond these ranges of wood density and moisture content, it is not advisable to apply these regression equations.

The estimated strength values from these regression equations will enable comparisons between species to be made and provide fast and reasonably reliable basic data. Nevertheless, it is suggested that individual species should be tested by strength testing machine whenever possible, so as to provide more accurate and complete information.

As the samples used were small clear specimens, it should be noted that the calculated data cannot be directly employed for design purposes. For this reason, the basic data are used in conjunction with the standard deviation in the derivation of the working stresses that were published in design specifications and building codes (Engku 1980).

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APPENDIX 1

Species and the number of tests to determine the species means (Green/Air dry)

Acacia auriculaeformis (3/3), *Adinandra dumosa* (12/12), *Agathis dammara* (3*/3*), *Albizia falcataria* (3/-), *Alselodaphne insignis* (3*/-), *Alstonia angustiloba* (3*/3*), *Amoora rubiginosa* (3*/3*), *Anisophyllea griffithii* (1/-), *Anisoptera laevis* (3/-), *Anisoptera marginata* (2/-), *Anthocephalus chinensis* (3*/3*), *Aquilaria malaccensis* (1/1), *Artocarpus lanceifolius* (3*/3*), *A. rigidus* (3/3), *A. scortechinii* (3/3), *Barringtonia pendula* (1/1), *Bertholletia excelsa* (1/-), *Bombax valetonii* (1/1), *Calophyllum curtisii* (3*/-), *C. inophyllum* (3*/-), *C. retusum* (5*/5*), *Campnosperma auriculata* (5/5), *C. coriacea* (1/-), *Canarium littorale* f. rufum (3*/-), *C. megalathum* (1/1), *Cantleya corniculata* (1*/1*), *Carallia* spp. (1/1), *Castanopsis malaccensis* (1/-), *Casuarina equisetifolia* (3/3), *Cedrela glaziovii* (1/-), *C. sureni* (1/-), *Chukrassia tabularis* (1/1), *Cocos nucifera* (3/3), *Coelostegia griffithii* (1/1), *Cratoxylon arborescens* (5/-), *C. formosum* (1/1), *Ctenolophon parvifolius* (3*/3*), *Cynometra malaccensis* (5/5), *Dehassia nigrescens* (3*/-), *Dialium platysepalum* (3*/3*), *D. patens* (1/-), *D. wallichii* (1/-), *Dillenia grandifolia* (3/-), *Dipterocarpus baudii* (5/5), *D. cornutus* (5/5), *D. crinitus* (1/1), *D. grandiflorus* (1/1), *D. kerrii* (1*/1*), *D. kunstleri* (1/-), *D. lowii* (1/1), *D. sublamellatus* (1/1), *D. varrucosus* (1/1), *Dryobalanops aromatica* (5/5), *D. oblongifolia* (5/-), *Durio oxyleyanus* (3/3), *Dyera costulata* (3/3), *Elaeocarpus sphaericus* (1*/1*), *Elateriospermum tapos* (3*/-), *Endospermum malaccense* (1/-), *Enterolobium cyclocarpum* (2*/2*), *Eucalyptus deglupta* (1/-), *E. robusta* (10/10), *Eugenia griffithii* (3*/3), *Fagraea crenulata* (3/3), *Ficus callosa* (1*/1), *Fragraea fragrans* (2*/-), *Ganua motleyana* (1*/-), *Gmelina arborea* (5/5), *Gnetum gnemon* (1*/-), *Gonystylus bancanus* (5*/5*), *Heritiera javanica* (1/-), *H. simplicifolia* (1/1), *Hevea braziliensis* (3*/3), *Homalium longifolium* (3*/-), *Hopea helferi* (3/3), *H. nervosa* (5/-), *H. nutans* (5/-), *H. sulcata* (5/-), *Hymenaea courbaril* (2/-), *Intsia palembanica* (5/5), *Irvingia malayana* (3*/3*), *Kokoona littoratis* (1/-), *Koompassia excelsa* (5/5), *K. malaccensis* (5/5), *Litsea firma* (3/3), *Litsea magnifica* (1/-), *Litsea megacarpa* (3*/-), *Lophopetalum floribundum* (3/3), *L. subovatum* (3/3), *Madhuca utilis* (5/5), *Maesopsis eminii* (3*/3*), *Mallotus muticus* (2/2), *Mangifera foetida* (3/3), *M. indica* (1*/1*), *Mangifera* spp. (3*/-), *Mastixia pentandra* (2/-), *Melanorrhoea torquata* (3/3), *Memecylon pubescens* (3*/3*), *Mesua ferrea* (3/3), *Mezzettia leptopoda* (3/3), *Monocarppia marginalis* (3/3), *Myristica gigantea* (3*/3*), *Myristica maingayi* (1/-), *Neesia altissima* (3/3), *Neobalanocarpus heimii* (5/5), *Ochanostachys amentacea* (3*/3*), *Palaquium gutta* (3*/3*), *P. hispidum* (1/-), *P. impressinervium* (4/4), *P. maingayi* (3*/3*), *Parartocarpus triandra* (3/3), *Parashorea lucida* (5/-), *P. densiflora* (1/-), *Parastemon urophhyllum* (3*/3*), *Parinari rubiginosum* (5*/5*), *Parkia speciosa* (3*/3*), *Pentace triptera* (3*/3*), *Pentaspadon velutinus* (4/-), *Pinus caribaea* (14*/14*), *P. insularis* (10*/10*), *P. merkusii* (15*/15*), *Pithecellobium confertum (3/3)*, *Planchonella maingayi* (1/-), *Pometia pinnata* (3*/3*), *P. pinnata* f. ridleyi (2/2), *Pterocarpus indicus* (1*/-), *Pterospermum javanicum* (1/1), *Pterygota horsfieldii* (1/-), *Quercus argentata* (1/1), *Q. lamponga* (3*/3*), *Rhizophora apiculata* (-/1*), *Santiria laevigata* (4*/4*), *Sapium baccatum* (3*/-), *Saraca thaipingensis* (3*/-), *Scaphium macropodum* (3*/3*), *Scorodocarpus borneensis* (4/4), *Schima wallichii* (3/3), *Shorea acuminata* (6/-), *S. bracteolata* (6/6*), *S. curtisii* (5/5), *S. faguetiana* (2/-), *S. glauca* (5/-), *S. hemsleyana* (3*/3*), *S. hypochra* (5/5), *S. kunstleri* (5/-), *S. laevis* (5/5), *S. leprosula* (5/5), *S. longisperma* (5/-), *S. macrophylla* (3*/3*), *S. macroptera* (5/-), *S. maxwelliana* (5/-), *S. multiflora* (3*/3*), *S. ochrophloia* (3/3), *S. parvifolia* (5/5), *S. pauciflora* (5/-), *S. platyclados* (5/5), *S. quiso* (6*/6*), *S. roxburghii* (6/6), *S. sericeiflora* (3/3), *S. singkawang* (1/1), *S. teysmanniana* (2/-), *S. uliginosa* (5/-), *Sindora coriacea* (3/3), *Streblus elongatus* (3*/3*), *Strombosia javanica* (3*/3*), *Swietenia macrophylla* (3/-), *Swintonia penangiana* (3/3), *S. schwenkii* (5/5), *S. spicifera* (3*/3*), *Tectona grandis* (9/9), *Terminalia bellirica* (1/1), *T. subspathulata* (1/1), *Tetramerista glabra* (1/1), *Vatica cuspidata* (5/-), *V. stapfiana* (5/-), *Xanthophyllum verucosum* (4/4), *Xylopia fusca* (4/4).

* One or more of the following properties have not been determined:
- Modulus of rupture
- Modulus of elasticity
- Impact bending
- Compression parallel to grain
- Compression perpendicular to grain
- Side hardness
- Shear parallel to grain
- Cleavage resistance to splitting in radial plane
- Cleavage resistance to splitting in tangential plane