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NON-LINIER COMPRESSION STRESS-STRAIN CURVE MODEL FOR HARDWOOD

Johannes Adhijoso Tjondro[1]*, Bambang Suryoatmono[1], Iswandi Imran[2]

[1]Civil Engineering Department Parahyangan Catholic University, Bandung, Indonesia
[2]Civil Engineering Department Bandung Institute of Technology, Bandung, Indonesia

ABSTRACT

Non-linier compression stress-strain relationship was derived from experimental investigation of 144 small clear specimens of three Indonesian hardwood species, namely Acacia, Meranti and Kruing. Both compression parallel to the grain and compression perpendicular to the grain were tested. The stress-strain curve consists of linier-elastic line until proportional limit and bi-linier curve. Stress-strain curve parameters for compression parallel to the grain, such as elastic modulus, post-elastic modulus, proportional limit, ultimate stress and post-elastic strain limit were derived based on the specific gravity. And also stress-strain curve parameters for compression perpendicular to the grain, such as elastic modulus, post-elastic modulus and proportional limit were derived based on the specific gravity and the angle between stress direction and tangential axis direction. Compression strength perpendicular to the grain in tangential direction was found much lower than compression strength perpendicular to the grain in radial direction.

Keywords: compression parallel to the grain, compression perpendicular to the grain, stress-strain curve, nonlinier curve model, post-elastic strain limit

1 INTRODUCTION

The development of finite element analysis, non-linier theory and computer technology brings the needs of non-linier stress-strain curve model. The compression strength parallel and perpendicular to the grain as the mechanical properties of wood were investigated from small clear specimens [2]. The equations for such strength were derived using multiple regressions based on the specific gravity (G) and the angle (θ) between the stress direction and tangential direction. The non-linear mechanical properties for compression parallel and perpendicular to the grain, such as elastic modulus (E_e), post-elastic modulus (E_p), yield stress (F_{cy}), ultimate stress (F_{cu}) and post-elastic strain limit (ϵ_{cu}) also presented in this paper.

Table 1. Range and average of specimen specific gravity

species	G	$G_{average}$	CoV(%)
Acacia	0.41 - 0.59	0.48	11.5
Meranti	0.49 - 0.62	0.57	5.5
Kruing	0.56 - 0.73	0.65	6.2
N=144			

*Corresponding author. e-mail: tjondro@unpar.ac.id

2 MATERIAL AND METHOD

Material was taken from the common building material supplier, three Indonesian hardwood species have been used, namely Acacia, Meranti and Keruing. The specific gravity was observed after the specimen was tested. The range of the specimens specific gravity was 0.41-0.73 such as in Table 1.

3 METHOD

This method based on testing data and statistical analysis.

Compression strength paralel to the grain test:
Compression parallel to the grain specimen dimension was 50 mm x 50 mm x 200 mm based on the ASTM D143-94 [1]. The movement of the crosshead control by strain rate of 0.003 mm/mm per minute or displacement rate 0.6 mm/minute. The test stopped after the failure of the specimen.

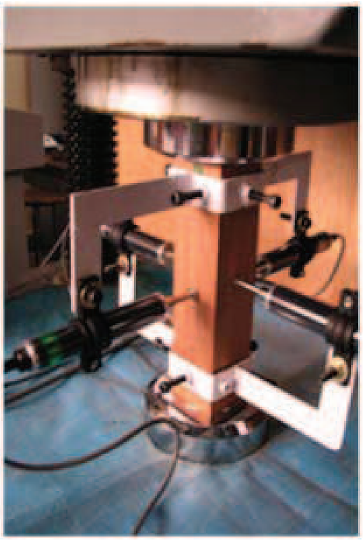

Figure 1. Compression parallel to the grain specimen under loading test.

Compression strength perpendicular to the grain:

Compression perpendicular to the grain specimen dimension was 50 mm x 50 mm x 150 mm based on the ASTM D143-94. The movement of the crosshead control by displacement rate of 0.305 mm/minute. The loading metal bearing plate with 50 mm x 50 mm surface contact to the specimen. The test was stopped at 2.5 mm displacement.

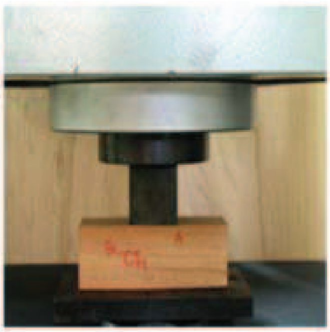

Figure 2. Compression perpendicular to the grain specimen under loading test.

4 RESULT AND DISCUSSION

Compression paralel to the grain test:

Figure 3 was typical test results of compression stress-strain curve paralel to the grain for different wood species and specific gravity. $F_{cy//}$ defined as compression strength paralel to the grain at proportional limit. The maximum average strain occured at the tests achieved 0.015. Bi-linier curve model as in figure 4 was proposed as a non-linier model of compression stress-strain curve paralel to the grain.

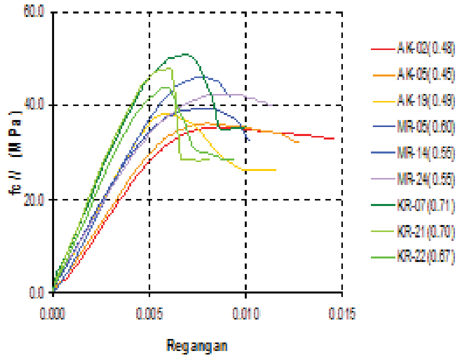

Figure 3. Typical compression stress-strain curve paralel to the grain.

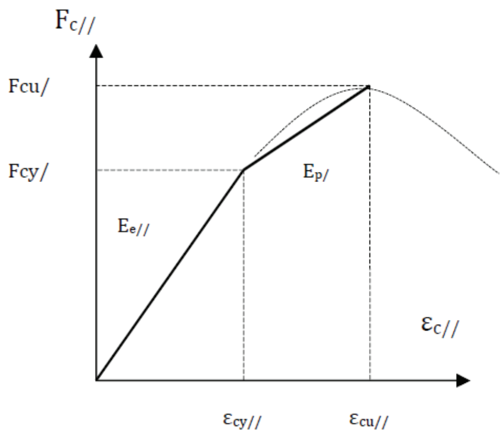

Figure 4. Bi-linier curve model for compression stressstrain paralel to the grain.

Data of all parameters in the curve of each samples as in the figure 3 was investigated and collected. This data which is correlated with specific gravity will be used in the statistical analysis. Parameters to set the curve model in the figure 4 was calculated by the equations resulted from the statistical analysis as below:

$$F_{cu//} = 72.1G^{0.95} \quad (1)$$

$$F_{cy//} = 62.4G^{1.20} \quad (2)$$

$$E_{e//} = 15052G^{1.20} \quad (3)$$

$$E_{p//} = 5777G^{1.16} \quad (4)$$

$$\epsilon_{cy//} = 0.0042G^{-0.13} \quad (5)$$

$$\epsilon_{cu//} = 0.0058G^{-0.36} \quad (6)$$

The corelations between $F_{cy//} - F_{cu//}$, $E_{p//} - E_{e//}$ and $\epsilon_{cy//}$ - $\epsilon_{cu//}$ as the following equations:

$$F_{cy//} = 0.59F_{cu//}{}^{1.08} \quad (7)$$

$$E_{p//} = 0.72E_{e//}{}^{0.93} \quad (8)$$

$$\epsilon_{cy//} = 0.04\epsilon_{cu//}{}^{0.44} \quad (9)$$

The value of R-square for $F_{cu//}, F_{cy//}, E_{e//}, E_{p//}, \epsilon_{cy//}, \epsilon_{cu//}$, were 0.661, 0.721, 0.913, 0.625, 0.057 and 0.203 respectively. And the R-square for corelation between $F_{cy//} - F_{cu//}$, $E_{p//} - E_{e//}$ and $\epsilon_{cy//} - \epsilon_{cu//}$ were 0.939, 0.665 and 0.397. The result of the equations (5) and (6) although has a small R-square still has a closed strain value compare to equations (10) and (11) respectively.

$$\epsilon'_{cy//} = \frac{F_{cy//}}{E_{e//}} \tag{10}$$

$$\epsilon'_{cu//} = \epsilon_{cy//} \frac{F_{cu//} - F_{cy//}}{E_{p//}} \tag{11}$$

where $\mathbf{r}_\alpha = \frac{F_{cy//}}{F_{cu//}}, \mathbf{r}_\beta = \frac{\epsilon_{cy//}}{\epsilon_{cu//}}, \mathbf{r}_\gamma = \frac{E_{p//}}{E_{e//}}$ and $\mathbf{r}_\alpha > \mathbf{r}_\beta > \mathbf{r}_\gamma < 1$.

The corelation of $\mathbf{r}_\alpha$, $\mathbf{r}_\beta$, and $\mathbf{r}_\gamma$ were derived from the bi-linier curve model in the figure 4, Tjondro, 2007. The correllation as the equation (12).

$$\mathbf{r}_\alpha \mathbf{r}_\beta - \mathbf{r}_\alpha \mathbf{r}_\gamma - \mathbf{r}_\alpha \mathbf{r}_\beta \mathbf{r}_\gamma - \mathbf{r}_\beta = 0 \tag{12}$$

The poisson ratio observed from the compression test paralel to the grain was presented in Table 2. The schematic of data measurement as in figure 5. Deformation in the R (radial) and T (tangential) direction was measured by LVDT-1 - LVDT-2 and LVDT-3 - LVDT-4 respectively.

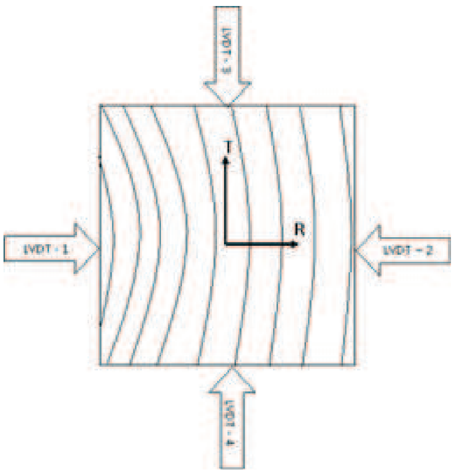

Figure 5. LVDT setting for radial and tangential direction.

The poisson ratios ν_{LT} and ν_{LR} calculated by the following equations:

$$\nu_{LT} = \frac{\epsilon_T}{\epsilon_L} \tag{13}$$

$$\nu_{LR} = \frac{\epsilon_R}{\epsilon_L} \tag{14}$$

Table 2. Average poisson ratio.

Species	ν_{LT}	ν_{LR}
Acacia	0.375	0.240
Meranti	0.324	0.172
Kruing	0.469	0.278
N=3x6=18		

Compression perpendicular to the grain test: Figure 6 was typical test results of compression stress-strain curve perpendicular to the grain for different wood species and specific gravity. $F_{cy//}$ defined as compression strength paralel to the grain at yield. Bilinier curve model as in Figure 7 was proposed as a non-linier model of compression stress-strain curve perpendicular to the grain.

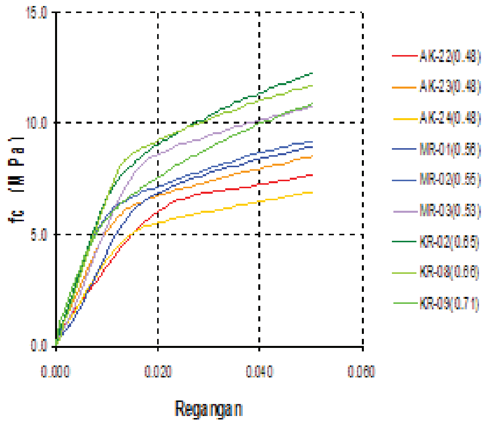

Figure 6. Typical compression stress-strain curve perpendicular to the grain.

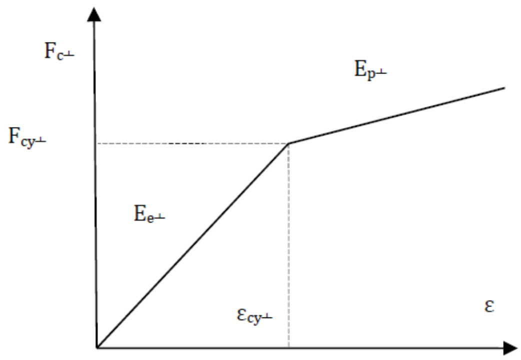

Figure 7. Bi-linier curve model for compression stressstrain perpendicular to the grain.

Parameters equation was found by the statistical analysis as was done for compression parallel to the grain curve model. The parameters were:

$$F_{cy\perp} = 11.48G^{0.72}\theta^{0.10} \tag{15}$$

$$E_{e\perp} = 1318G^{1.56}\theta^{0.10} \tag{16}$$

$$E_{p\perp} = 295G^{2.61}\theta^{0.03} \tag{17}$$

$$\epsilon_{cy//} = 0.0065G^{-1.16}\theta^{0.05} \tag{18}$$

The corelations between $E_{p\perp} - E_{e\perp}$ as the following equations:

$$E_{p\perp} = 0.011E_{e\perp}^{1.38} \tag{19}$$

$$E_{p\theta\perp} = 0.013E_{e\perp}^{1.35}\theta^{0.02} \tag{20}$$

The value of R-square for $F_{cy\perp}, E_{e\perp}, E_{p\perp}, \epsilon_{cy//}$ were 0.684, 0.793, 0.895 and 0.463 respectively. And

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the R-square for corelation between $E_{p\perp} - E_{e\perp}$ and $E_{p\theta\perp} - (E_{e\perp}, \theta)$ were 0.747 dan 0.753 respectively. The result of the equation (18) although has a small R-square still has a closed strain value compare to the equations (21).

$$\epsilon_{cy\perp} = \frac{F_{cy\perp}}{E_{e\perp}} \tag{21}$$

The effect of angle between stress direction to the tangensial axis θ was significant, the $F_{cy\perp}$ with θ =4° 30% smaller than $F_{cy\perp}$ with θ = 90°.

5 CONCLUSION

1. The equations (1) to (12) may be used to set the non-linier stress-strain curve model for parallel to the grain and (15) to (21) for perpendicular to the grain.
2. The ultimate strain ϵ_{cu} (6) may be set as strain limit at failure for compression parallel to the grain.
3. The compression strength perpendicular to the grain much lower than compression strength parallel to the grain
4. The compression strength perpendicular to the grain at radial direction approximately 30% higher than in the tangensial direction.

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