FRACTURE TOUGHNESS AND TENSION SOFTENING PROPERTIES OF GLUED LAMINATED TIMBERS

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Applicability of LEFM to glued laminated timbers was studied. Since a certain amount of energy is absorbed in woods even after a crack initiates, a linear fracture mechanics parameter such as K_{IC} and G_{IC} may give an underestimated fracture toughness.

J-based test method recently developed by Li may be available to woods. This method can give not only the critical value of J_{IC} but also tension softening diagram which is essential to analyses of nonlinear behavior due to cracking.

INTRODUCTION

In order to study the cracking properties, fracture mechanics approaches have been recently applied to woods(1,2). Linear elastic fracture mechanics (LEFM), however, can be applicable only when the nonlinearity of the solid around the crack tip is negligible. Since the structure of wood is very heterogeneous and wood is not strictly speaking a linear-elastic solid, it is doubtful if LEFM is applicable to wood.

In this paper, fracture toughness and tension softening properties (Figure 1) of glued laminated timbers are discussed by using the J-based test method recently proposed by V.C. Li (3). These properties are essential when the nonlinear behaviour due to cracking of timber structures is analyzed by FEM.

EXPERIMENTAL PROCEDURES

Four types of woods were tested, which were Douglas fir, Japanese cedar, spruce and larch. Compact tension specimens with different notch lengths (70 and 80 mm) were used under cyclic tensile loads. The geometry and dimension of specimens are shown in Figure 2 and

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TABLE 1. While notches were given in two different directions, Type P specimens have a notch parallel to the laminae and Type A specimens have a notch crossing the laminae. Every three specimens were tested for each condition. Loading and measuring equipments are shown in Figure 3. Fundamental properties of wood specimens are shown in TABLE 2.

TABLE 1 - Dimension of Specimens. (mm)

	Thickness of laminar	h	b	W		a
				Type P	Type A	
Douglas fir	36	150	75	150	150	70, 80
Japanese cedar	21	150	75	140	150	70, 80
Spruce	20	150	75	160	150	70, 80
Larch	24	150	75	150	150	70, 80

TABLE - 2 Fundamental Properties of Tested Woods.

	Specific Gravity *	Water Cont. (%)	Compress. Strength (MPa)	Compressive ** Young's Moduli. (GPa)
Douglas fir	0.50	11.6	46.2	14.3
Japanese cedar	0.40	13.1	31.5	8.7
Spruce	0.40	11.1	34.4	9.1
Larch	0.54	9.6	50.1	13.2

* Air dried specific gravity.
** E in the longitudinal direction along the grain.

EXPERIMENTAL RESULTS AND DISCUSSION

Load - loading point displacement curves and load - crack opening displacement curves were obtained as the envelope curves of cyclic ones. According to the analytical procedure shown in Figure 4, J - δ relationships and tension softening diagrams such as Figure 5 were obtained.

TABLEs 3 and 4 show the mean values of strength properties of each type of specimens and the corresponding fracture parameters. σ_n^l is the nominal flexural stress at the proportional limit point, while σ_n^u means the nominal flexural strength calculated from the maximum load acting on the ligament at the crack tip. f_t is the tensile strength obtained from the peak cohesive stress in the tension softening diagram. J_c* and J_c** are the critical values of J-integral by means of Li's method and Merkle & Corten equation,

TABLE 3 - Strength Properties.

		a (mm)	σ_n^l (MPa)	σ_n^u (MPa)	f_t (MPa)
P	Douglas fir	70	1.78	2.11	3.63
		80	1.39	2.15	
	Japanese cedar	70	1.05	1.69	2.55
		80	1.27	1.78	
	Spruce	70	1.42	1.98	3.33
		80	1.60	1.98	
	Larch	70	1.58	2.39	3.82
		80	1.49	2.71	
A	Douglas fir	70	0.86	1.76	1.37
		80	1.04	1.88	
	Japanese cedar	70	1.33	1.88	1.08
		80	1.58	2.13	
	Spruce	70	0.97	1.45	2.06
		80	1.14	1.64	
	Larch	70	1.41	2.15	3.73
		80	1.84	2.39	

σ_n^l: nominal flexural stress at the proportional limit point of the load-deflection curve.

σ_n^u: nominal flexural stress at the peak of the load-deflection curve.

TABLE 4 - Fracture Toughness Properties.

		a (mm)	J_C* (J/m^2)	J_C** (J/m^2)
P	Douglas fir	70	231.4	159.8
		80		147.1
	Japanese cedar	70	254.0	171.6
		80		154.0
	Spruce	70	357.9	197.1
		80		158.9
	Larch	70	304.0	193.2
		80		211.8
A	Douglas fir	70	336.4	214.8
		80		180.4
	Japanese cedar	70	307.9	180.4
		80		161.8
	Spruce	70	354.0	112.8
		80		122.6
	Larch	70	152.0	115.7
		80		142.2

where

J_C*: critical value of J-integral by Li's method

J_C**: critical value of J-integral by Merkle & Corten's equation respectively. While J_c** is evaluated from the absorbed energy up to the maximum load, J_c** should coincide with G_c in case of linear elastic solids (J_c** $\geq G_c$).

According to TABLE 3, tensile strength f_t of Type P specimen is larger than that of Type A specimen for all cases. In cases except larch, load -loading point displacement curves of Type P have rather pointed shapes and cohesive stress abruptly decreases up to about 10 % of f_t when the separation width reaches about 0.1 or 0.2 mm. On the other hand, cohesive stress of Type A decreases slowly as δ increases though values of f_t are rather small.

TABLE 4 shows that values of J_c** are much less than those of J_c*. It means that a large amount of energy is absorbed even after the maximum load in case of woods. Even if tensile strength of Type A is lower than that of Type P, J_c* of Type A is about the same (spruce) or even larger (Douglas fir and Japanese cedar) than that of Type P. Only larch showed a different tendency from that of other kinds of woods. From these results, Type A specimens except larch used here have higher toughness than Type P specimens.

In case of Type P, σ_n^u and f_t are rather proportional to the specific gravity. In case of Type A, however, these relations have very wide scatters. Moreover, no relationships in both types can be recognized between J_c* or J_c** and the specific gravity.

While grain width may have a dominant correlation with the crack opening displacement, dense grain distribution leads to a small crack opening displacement and a finely uneven surface was observed on the cracked surface. The variety of grain width and grain orientation in laminar by laminae influences a lot on the cracking behaviour. Existence of knots in the crack surface causes a significant influence, too.

CONCLUDING REMARKS

In order to evaluate cracking properties of glued laminated timbers, a fracture mechanics approach was applied. The following remarks were obtained: 1). since a certain amount of energy is absorbed even after a crack initiates, a linear fracture mechanics parameter such as K_{IC} and G_{IC} leads to under-estimation of the fracture toughness; 2). a J-based test method recently developed by Li may be available to woods. This method can give not only the critical value of J_{IC} but also a tension softening diagram which is essential to analyses of nonlinear behaviour due to cracking.

REFERENCES

(1). Barrett, J.D., Phil. Trans. R. Soc. Lond., A 299, 1981, pp. 217-226 .

(2). Jodin, Ph. et al., Fracture Mechanics Applied to Wood, "Fracture of Non-Metallic Materials", Edited by K.P. Herrmann et al., D. Reidel Publishing Company, 1987.

(3). Li, V.C. et al., Cement and Concrete Research, vol. 17, 1987, pp. 441-452.

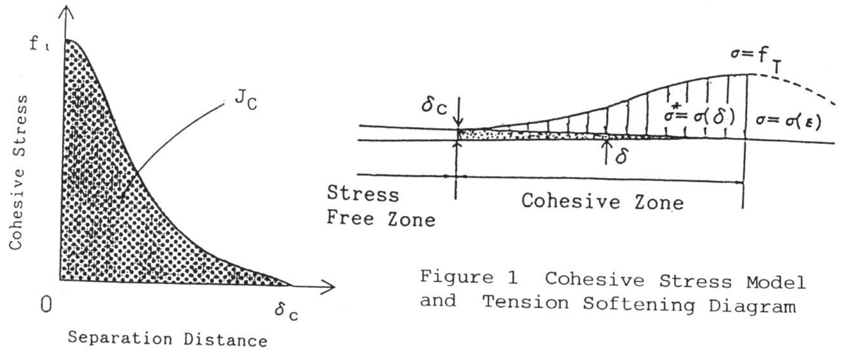

Figure 1 Cohesive Stress Model and Tension Softening Diagram

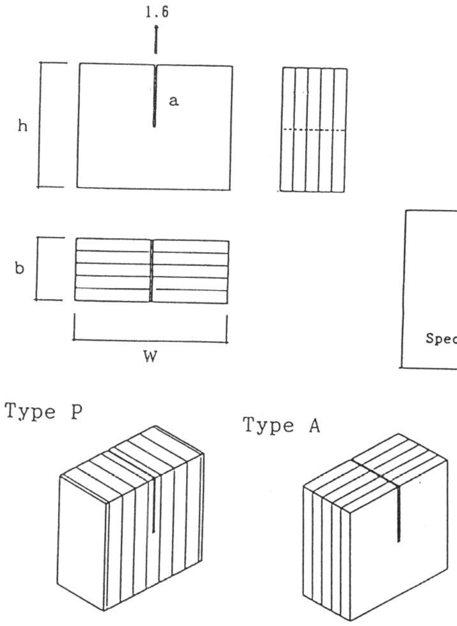

Figure 2 Geometry of Specimens and Notch Arrangement

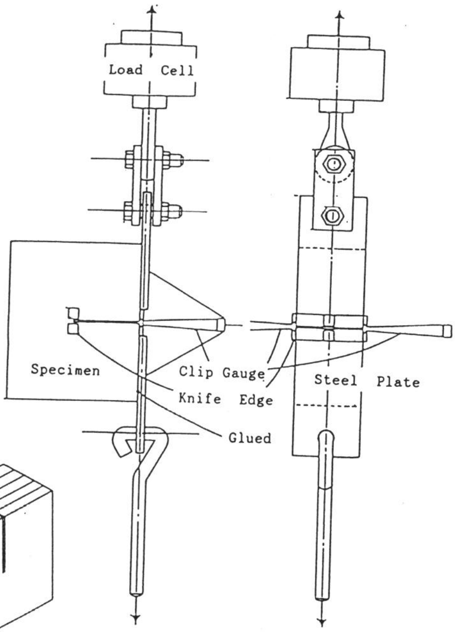

Figure 3 Loading and Measuring Equipments

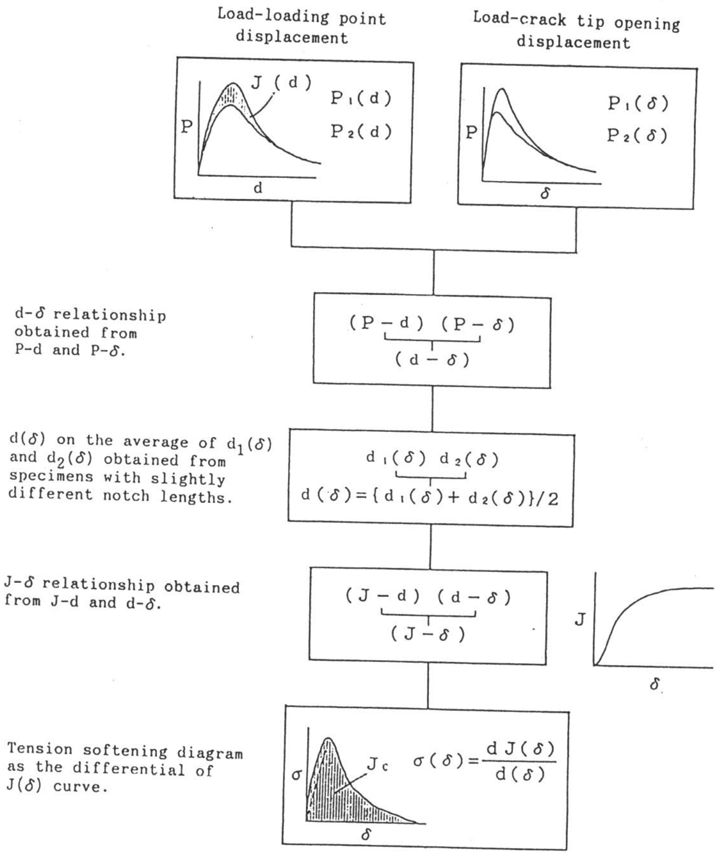

Figure 4 Analytical Procedure

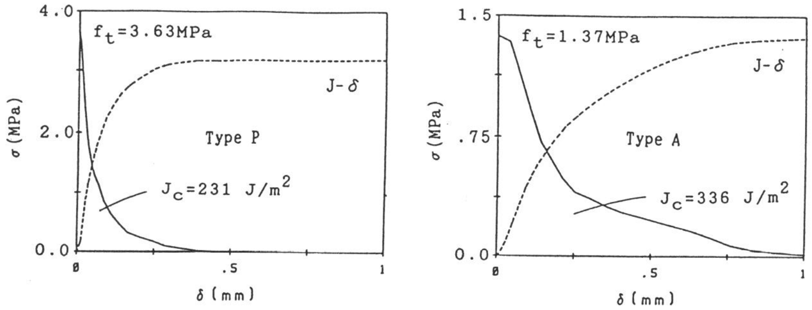

Figure 5 J- and Tension Softening Diagram of Douglas Fir