Karyadi, Sri Murni Dewi, Agoes Soehardjono Md / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp.2614-2619

Experimental Investigation on Characteristics of Mechanics of Box-Section Beam Made Of Sliced-Laminated Dendrocalamus Asper under Torsion

Karyadi[1], Sri Murni Dewi[2], Agoes Soehardjono Md[3],
[1]Doctoral Student at Master and Doctoral Program, Faculty of Engineering, Brawijaya Unversity, Indonesia and Lecturer at Civil Engineering, Faculty of Engineering, Malang State University, Indonesia.
[2]Professor at Civil Engineering Depertement, Faculty of Engineering, Brawijaya University, Indonesia
[3]Professor at Civil Engineering Departement, Faculty of Engineering, Brawijaya University, Indonesia

ABSTRACT

This study has investigated the box-section beam under torsion. Eight beams made of Dendrocalamus asper were laminated and bonded with 268g/m^2 of urea formaldehyde. The beams were then cool-pressed by 2MPa for 4 hours. The section size of the beams are 80mm, 120mm, and 160mm with 15mm, 20mm, and 25mm of thickness. The results showed that the maximum shear stress occured in the range of 4.39Mpa to 10.13 MPa with a mean of 6.50 MPa. Shear modulus of beam occured in the range of 690.68MPa to 1072.28 MPa with the mean of 902.10MPa

***Keywords* -** Dendrocalamus Asper, Experimental, Laminate, , Torsion.

I. INTRODUCTION

Fulfilling the needs of timber for building construction has reached 1.8 billion m^3 per year, caused pressures on the forestry sector. This situation led to the loss of the forest that reached 0.71% per year during 2000-2010 [1].

To reduce the dependence on wood as building materials, it is necessary to find a replacement that has similarities with wood properties; physics, mechanics, and its appearance. Dendrocalamus asper becker with a specific gravity at 12% moisture content of 0.55 to 0.90, modulus of rupture (MOR) 198.52MPa, modulus of elasticity (MOE) 15,363Mpa and compressive strength perpendicular to the grain 14. 39Mpa [2] has an equivalence strength class with wooden D50 [3]. Therefore Dendrocalamus asper becker can be promoted as building materials to substitute woods.

Research on the use of bamboo for the beams have been carried out [4], [5], [6], [7], but these studies only examined the behavior of the beams due to bending and none of those examined the behavior of the beams under torsion. On the other hand, torsional much happened on structures, for example in the case of torsion beam, torsional buckling, lateral-torsional buckling, and flexure-torsional buckling [8].

To improve the efficiency of the use of the materials, this study examined the torsion capacity of box-section beams. Box section will provide a greater moment of inertia than the solid cross-section for the same cross-sectional area [9].

Torsional behavior on the box section can be analyzed by using thin-walled beams with the formulas which have been widely written in books of mechanics of materials [9], [10]. The relationship between torque (T), shear stress (τ) and cross-sectional properties expressed in the formula,

$$\tau = \frac{T}{2tA_m} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

where t is the thickness of the wall of the beams and A$_m$ is the area bounded by a line through the middle of the thickness of the beam. Further, angle of twist (φ) that occur on the beam due to the torque (T) calculated by the formula,

$$\phi = \frac{TL}{GK_T} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

where L is the length of the beam, G is the shear modulus, K_T is the torsional constant and GK_T referred torsional rigidity. The above formula just valid for thin-walled beams with a ratio between width of cross sectional and wall thickness greater than or equal to 10 [11].

For a box-section beam with a ratio between cross-sectioned width and thickness of the wall greater than or equal to 2, formulas of Pekgokgoz and Gurel are used [12]. The relationship between shear stress (τ), Torque (T), wide cross-section (a), and wall thickness (t) is denoted by,

$$\tau_{\max} = \frac{T}{W_T} \quad \dots\dots\dots\dots\dots\dots \quad (3)$$

$$W_T = a^3\left(1{,}864\left(\frac{t}{a}\right) - 5{,}340\left(\frac{t}{a}\right)^2 + \left(\frac{t}{a}\right)^3\right) \quad \dots\dots \quad (4)$$

Table 1. Actual Beam Dimensions

Designator	Dimension (mm)												Span length (mm)	Gauge length (mm)
	Left end						Right end							
	h	b	t1	t2	t3	t4	h	b	t1	t2	t3	t4		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T.8.12	80	81	12	12	12	12	80	81	12	12	12	12	640	480
T.8.17	80	80	17	17	17	17	80	80	17	17	17	16	960	800
T.8.22	81	80	22	22	21	21	81	80	22	22	21	21	800	640
T.12.12	121	121	13	13	12	12	119	121	12	12	12	12	1200	960
T.12.17	121	121	17	17	17	17	121	121	18	17	18	18	960	720
T.12.22	121	121	22	22	22	22	120	121	22	21	22	22	1440	1200
T.16.12	160	161	12	12	12	12	160	159	12	12	12	12	1920	1600
T.16.22	159	159	22	22	22	22	158	160	22	22	22	22	1280	960

Furthermore, the angle of twist per unit length (ω) caused by the torque (T) is calculated by the formula,

$$\omega = \frac{T}{GK_T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where G is the shear modulus and KT is the torque constant is calculated by the formula,

$$K_T = a^4\left(0{,}978\left(\frac{t}{a}\right) - 2{,}309\left(\frac{t}{a}\right)^2 + 1{,}826\left(\frac{t}{a}\right)^3\right) \quad \ldots.\ (6)$$

The purpose of this study is to determine the mechanical characteristics of box-section beam made of sliced-laminated Dendrocalamus asper under torsion. Mechanical characteristics may include a maximum capacity of beams in receiving torque, shear stress, and shear modulus obtained through experimental study.

II. MATERIALS AND METHODS

The raw material of this study is Dendrocalamus asper with the age range of 3-4 years which were taken from Malang, East Java, Indonesia. The raw materials were used in the form of sliced with cross-sectional size of 5mm thick, 20mm wide, with length ranging from 840mm to 1480mm. Given the bamboo wall thickness varied from lower to upper part, a sliced with 5mm of thickness was taken from the part that is closest to the skin. It is expected that the sliceds have nearly uniform physical and mechanical characteristics. The sliced were then preserved by soaking it in a solution of tetra sodium borax ($Na2B4O2$) with the concentration of 1% for 24 hours.

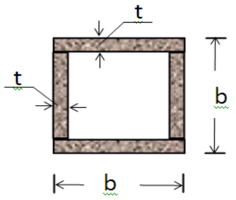
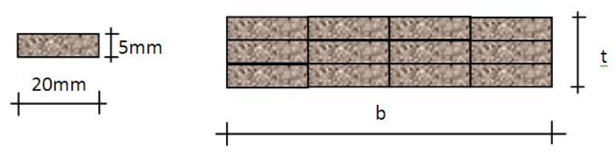


Figure 1. Cross section of box-beam

Box-section beam specimens (Fig. 1) were made in three size of wide section (b): 80mm, 120mm, and 160mm which represents measure of the timber mostly used in building construction. The wall thickness (t) was made in three sizes: 12mm, 17mm, and 22mm. The span of the beams was set at least eight times of the size of the wide section [13]. To support beams during testing, additional 2 x 100mm of length was added. Further, gauge length is the distance from the inclinometer at the left end to the inclinometer on the right end. The actual size of eight beams specimen are listed in Table 1.

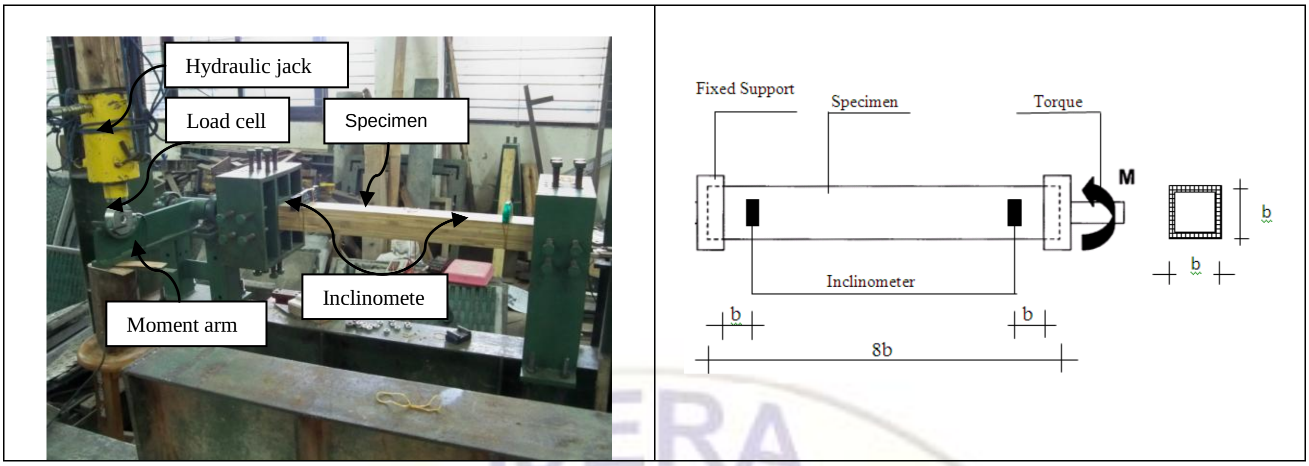
The beam walls were made of sliced bamboo and were glued to each other as shown on the Fig. 2. Bonding is done with urea formaldehyde at the application rate 268g/m^2 and cold-pressed by 2MPa for 4 hours [14]. The amount of sliced bamboo glued was adjusted to the size of the beams wall thickness (t) and the width of the beam at cross section (b).



(a) (b)

Figure 2 (a) sliced Bamboo, (b) laminated-Bamboo

Torsion testing was done by referring to the Annual Book of ASTM Standards Volume 4:10: D 198-02 of the Standard Test Method of Test Statics Lumber in Structural Sizes, Section 36-43 [13]. Two type of support were needed during testing: one fixed support and one spinning support to apply torque. The torque was generated from the hydraulic jack with capacity of 5ton, with 400mm long arm twisting. In order to measure the angle of twist, two inclinometer was placed at distance b from the ends of the support as shown in Fig. 3.



(a) (b).

Figure 3. a) Torsion test apparatus b) Torsion test arrangements

The maximum capacity of the beam is defined as the maximum torque that causes the beam collapse, and characterized by the loss of the ability to receive the torque. Shear stress that occurs in the beam is calculated based on the maximum capacity of the beam by using formula (3). Furthermore, shear modulus obtained from the part of linear graph of the relationship between torque and angle of twist per unit length was calculated by formula (5).

III. RESULTS AND DISCUSSION

Torsional testing in this study results in main data in the form of the relationship between torque and angle of twist per unit length of the beam (Fig. 4). Loading procedur was conducted from zero torque and was gradually increased by 20,000Nmm until the beam collapsed. The magnitude of the torque (Nmm) is obtained from the load cell readings which were multiplied by the moment arm and the magnitude of angle of twist (radians) is obtained from the difference between the two inclinometer readings which were divided by the gauge length. By using these two basic data, the analysis was performed to obtain the maximum torque, maximum angle of twist per unit length, the maximum shear stress, and shear modulus for each specimen. The maximum torque is defined as the torque that caused beam collapse. At the time when maximum torque was reached, maximum angle of twist was obtained too.

The graph in Fig. 4 shows that the relationship between torque and angle of twist per unit length is not linear. The linear part was taken to determine the magnitude of the shear modulus.

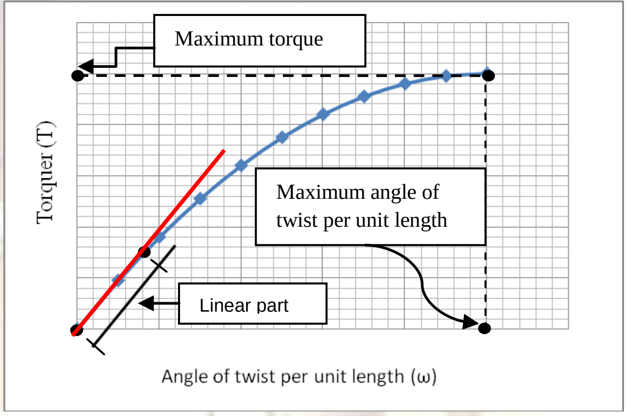


Figure 4 Relationships between torsion and angle of twist per unit length

Relationships Between Torsion and Angel of Twist

The testing on eight box-section beams shows that the relationship between torque and angles of twist are varied. Fig. (5) presents the graph that shows the relationship for beams with T.8.12 designator.

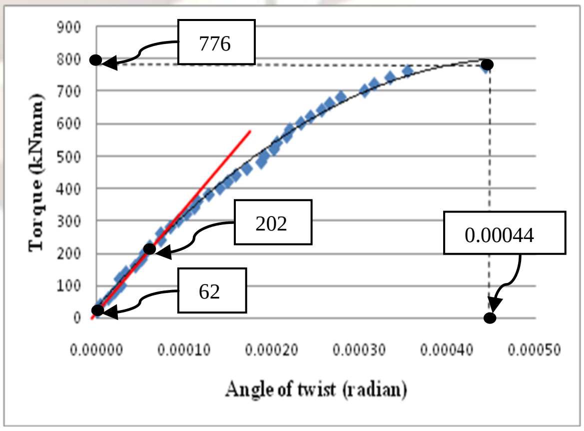


Figure 5. Relationship between torsion and angle of twist beam T.8.12 designator

To beam T.8.12 designator obtained 776kNmm maximum torque, maximum angle of twist per unit length is 0.00044 radians. Linear part starting from the moment the amount of 5% of the maximum torque (62kNmm) until the moment 25% of the maximum torque (202kNmm). In his research [15] found that the linear part of the graph of relationship between torque and angle of twist for wood samples Sitka spruce (Picea sitchensis) and Norway spruce wood (Picea abies) were in the range of 3% to 30% of maximum torque. Further, these magnitudes for the other beam specimen results are presented in Table 2.

Table 2. Experiment result

Designator	W_T (mm^3)	K_T (mm^4)	Maximum torque (Nmm)	Angel of twist maximum per unit length (radian)	Maximum Shear stress (MPa)	Mean of shear modulus (MPa)
1	2	3	4	5	6	7
T.8.12	90,251	4,133,284	776,000	0.00044	8.60	993.55
T.8.17	103,829	4,959,477	562,000	0.00017	5.41	1032.83
T.8.22	108,756	5,419,293	1,102,000	0.00030	10.13	1072.28
T.12.12	243,058	16,304,761	1,482,000	0.00021	6.10	873.37
T.12.17	301,696	20,769,527	1,922,000	0.00023	6.37	874.25
T.12.22	340,736	24,107,402	1,922,000	0.00014	5.64	772.21
T.16.12	458,200	40,063,611	2,442,000	0.00017	5.33	690.68
T.16.22	678,848	61,325,957	2,982,000	0.00003	4.39	907.64

Maximum Shear Strength

Uniform torque led to pure shear stress. Based on mechanical analysis, the maximum shear stress will be directed perpendicularly and parallel to the longitudinal axis of the beam. Concerning that the direction of grain of sliced bamboo which was made up the beam was placed in the direction of the longitudinal axis, it can be said that the maximum shear stress will be directed perpendicularly and parallel to the grain of sliced bamboo.

According to Table 2, the magnitude of the shear stress that occurs in the beam test varied from 4.39MPa to 10.13MPa with a mean of 6.50MPa. Variations in the magnitude of the shear stress were caused by variations in the strength of sliced bamboo that was made up the beam. Data of shear stress parallel to grain of dendrocalamus asper from three researchers that collected by [3] showed that the range of shear parallel to grain were extended from 5.35 MPa to 14Mpa. Furthermore, [16] examined the boards of laminated dendrocalamus asper with the mean shear stress of 7.32MPa.

When compared to wood, the minimum shear stress of 4.39MPa is equivalent to the softwood at strength class of C24 to C50 and is equivalent to the hardwood with strength class of D24 to D50 [3]. This result confirmed that the dendrocalamus asper can be used as wood substitutes.

Shear Modulus

Table 2 shows the result of shear modulus from this experiment that has range 690.68MPa to 1072.28MPa with a mean 902.10MPa. Until now there has been no study of shear modulus of bamboo, but as a comparison, a results of research by [15] that used wood samples Sitka spruce (Picea sitchensis) with strength class of C16 had obtained average shear modulus of 520MPa. For Norway spruce wood (Picea abies) with strength class of C16 obtained average shear modulus 610MPa and strength class of C24 obtained for the average shear modulus of 760MPa. When compared to wood, test result of shear modulus of sliced-laminated bamboo in this study is equivalent to the softwood at strength class of C24 to C50, and equivalent to the hardwood with strength class of D30 to D60 [3].

Mode of Beam Failure Under Torsion

The collapse of the beam under torsion occurs suddenly with loud noise. At the same time the ability of beam to resist torsion has lost and cracks occur parallel to the grain of sliced bamboo. These cracks are caused by shear stress parallel to the grain of bamboo which is the weakest part compared to the ability of bamboo to resist shear stress which is perpendicular to the grain.

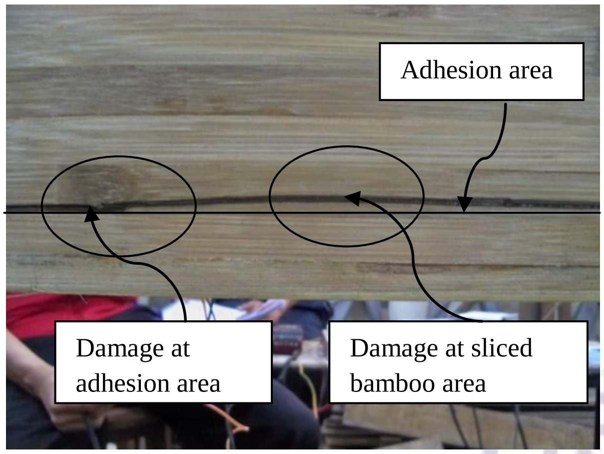


Figure 6. Photo of pattern of beam damage

Observations in the field crack show that cracks can occur in the are of adhesion or in the sliced bamboo (Fig. 6). Table 3 shows the percentage of damage at both places. At all the beam, damages occurred at the adhesion and the sliced bamboo and none occurred in the field of adhesion alone or on sliced bamboo. The greatest damage at adhesion area occurred on the beam with T.16.22 designator that is equal to 76.19% and the smallest on the beam with T.12.17 designator that is equal to 22:41%. The greatest damage at the sliced bamboo occurred on the beam with T.12.17 designator that is equal to 77.59% and the smallest occurred in the beam with T.16.22 designator that is equal to 23.81%. The mean of the eight beams suffered damage to areas of adhesion is.54.45%, and mean damage to the sliced bamboo is 45.55%. Rasio of percentage of damage at adhesion area and at sliced bamboo area are closer to 50% : 50% indicates that the adhesive and gluing process has provided optimum results.

Table 3. Percentage of Beams Damage

Designator	Damage (%)	
	Adhesion area	Sliced bamboo area
T.8.12	61.25	38.75
T.8.17	52.84	47.16
T.8.22	40.40	59.60
T.12.12	76.09	23.91
T.12.17	22.41	77.59
T.12.22	65.85	34.15
T.16.12	40.57	59.43
T.16.22	76.19	23.81

IV. CONCLUSIONS

This study concluded that from its ability to resist torsion, bamboo deserves to be promoted as a replacement for the wooden parts of the structure that receives torque. Magnitude of shear stress in the range of 4.39MPa to 10.13MPa with a mean of 6.50MPa and shear modulus in the range of 690.68Mpa to 1072.28Mpa with a mean of 902.10MPa showed that bamboo can be compared with the softwood and hardwood as regulated in Europe.

References

[1] FAO, *Global Forest Resources Assessment 2010* (Food and Agriculture Organization of The United Nations, Rome, 2010)

[2] Malanit, P., *The Suitability of Dendrocalamus Asper Becker for Oriented Strand Lumber*. A Thesis for The Degree of Doctor of Natural Science in Department of Biology Faculty of Mathematics, Information and Natural Science University Of Hamburg. 2009.

[3] EN338, *Structural Timber – Strength Classes*, European Committee for Standardization, Brussels. 2009.

[4] Lee, A.W.C., Bai, X., and Bangi, A.P., Flexure properties of bamboo-reinforced southern pine OSB beams. *Forest Products Journal. 47(6). 1997, 74-78.*

[5] Karyadi dan Suwarno, E.. Kajian Analitis dan Eksperimental Kekakuan dan Kekuatan Lentur Balok Laminasi dengan bahan kayu sengon dan Bambu Petung. *Jurnal Teknologi dan Kejuruan. **29**(2), 2006, 91-104.*

[6] Xiao, Y., Shan, B., Chen, G., Zhou, Q., Yang, R.Z., and She, L.Y., Development of Laminated Bamboo Modern Structures, *Proceeding of The 11th International Conference on Non-Conventional Materials and Tehnologies (NOCMAT 2009), 6-9 September 2009, Bath, UK., 2009.*

[7] Xiao, Y., Zhou, Q., and Shan, B., Design and construction of Modern Bamboo bridge. *Journal of Bridge Engineering **15**(5). 2010, 533-541.*

[8] Yoo, C.H. and Lee, S.C., *Stability of structures:* principles *and applications*, (Elsevier, Amsterdam, 2011).

[9] Gere, J.M. and Timoshenko, S.P., *Mechanic of material, Third SI Edition*. (Chapman and Hall. London, 1994).

[10] Boresi and Schmidt, *Advanced mechanics of Mmterials*. (John Wiley & Son, Inc. United States of America, 2003).

[11] Seaburg, P.A. and Carter, C.J., *Torsional Analysis of Structural* Steel *Members*, (American Institute of Steel Construction, Inc. The United States of America, 2003).

[12] Gurel, M. A. and Pekgokgoz, R. K., An Approximate Torsion Analysis of Closed Moderately Thick-Walled, Thick Walled, and Solid Cross-Section, *Turkish J. Eng. Env. Sci. 32(-) 2008, 277-287.*

[13] ASTM. 2003. *Annual Book of ASTM Standards Volume 04.10: D 198-02*

Standard Test Method of Statics Test of Lumber in Structural Sizes. (West Conshohocken, PA, USA, 2003)

[14] Masdar, A., Morisco, Prayitno, T.A., *Pengaruh posisi sambungan terhadap keruntuhan lentur balok bambu laminasi*. www.fab.utm.my/download/ConferenceSemiar/ICCI2006S2PP04.pdf. diakses 2 Pebruari 2011.

[15] Khokhar, A., Zhang, H., and Ellis, D., R., The Shear Strength and Failure Modes of Timber Joists Obtained from The Torsion Test Method. *Proceedings of World Conference on Timber Engineering*, 20th – 24th *June. Trentino Italy, 2010.*

[16] Manuhua, E. and Loiwatu, M., Mechanical and Physical Properties of The Laminated Board of Bamboo, *Proceedings The 2nd International Symposium of Indonesian Wood research Society*, *Indonesian Wood Society (IWoRS), 2010.*