Uniaxial Tension of Yellow Meranti Timber at an Angle to the Grain

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Abstract

Tensile strength measures the force applied to a timber element/structural element to the point where it breaks. In this paper, a finite element analysis (FEA) of uniaxial tension of Yellow Meranti timber (*Shorea spp.*), using von Mises Criterion to include orthotropic nature of the material, was used to derive a prediction of tensile strength at an angle to the grain (cross grain) in plane stress (2D) modeling. To investigate the validity of the finite element analysis results, various 5°, 10°, and 15° cross grain specimens of Yellow Meranti (*Shorea spp.*) were tested in laboratory under uniaxial tension stress using UTM instrument. Comparison with experimental results shows that the FEA simulation predicts the stress-strain curves lower than experimental results, which result shows good agreement, it is seen from %-relative difference which is less than 30%. Calculations were performed with the numerical analysis (FEA) and Experimental Tests gives results that the difference is not too significant, for specimens with a grain angle of 5° difference in outcomes by 27%, for a grain angle of 10° difference in outcomes by 25%, and for a grain angle 15° difference in outcomes by 22%.

Keywords: FEA, Uniaxial tension, Orthotropic, Yellow Meranti (*Shorea spp.*).

Introduction

Wood is a material that is used for many everyday purposes, used to make a variety of tools in various fields of life such as construction, field of furniture, household items, and so on. In the field of construction, the wooden structure is rarely found at this time, this is because the function of the structure of wood as a material role has been replaced by concrete and steel. Besides, wood obtained from trees whose presence decreases from year to year in the Indonesian forest. The use of wood in constructions, among others, is as a residential building, the roof of the houses, pedestrian bridges, sills, windows, and doors. Wooden buildings are still often found in Indonesia and overseas, this is due to factors still many traditional buildings and modern buildings are included in the category of classical. The use of wood in construction is more emphasis on how strong the appeal of wood in bearing the burden. For example on the house's roofs, timber receives a tensile load dominant force arising trunk load that was applied on the roof. In addition there is a load and tensile stress. However, in the present study only examined the tensile strength of Meranti timber.

Tensile strength of the wood itself is affected by several factors such as the mechanical properties of the wood itself. Mechanical factors here are the mechanical properties of wood that determine how strong the wood resists tensile loads. Mechanical properties of wood in general include elastic modulus, flexural strength, tensile strength, shear strength, compressive strength, hardness of wood and there's more mechanical properties of wood. Then, to determine the tensile strength of wood as a guide to the strength of wood in building a construction, required a study of the tensile strength of wood that can be done by means of numerical or experimental research. The results of the two will be compared to obtain a good level of validity.

Experimental tests and analytical research on the distortion energy criterion for timber uniaxial compression at an angle to the grain has been done previously (Pranata and Suryatmono 2012). Similar research has also been done using analytical approach and experimental tests, but for timber uniaxial tension at an angle to the grain (Suryatmono and Pranata 2011; Suryatmono and Pranata 2012). In the previous experimental tension tests, it was difficult to obtain the real tension strength for specimens at an angle to the grain. In general, failure occurred not at the plane perpendicular to the load, but at the principal plane of the material.

Numerical research on the distortion energy criterion for Red Meranti (*Shorea spp.*) timber uniaxial compression at an angle to the grain has also been done previously. A finite element analysis (FEA) based on a distortion energy criterion in an orthotropic material can be used to obtain the compressive strength at proportional limit for cross grain specimens, and an FEA incorporating Hill's yield criterion is a conservative method for predicting compressive strength at an angle to the grain (Pranata and Suryatmono 2013).

According to the ASTM D143 (ASTM 2008), procedure for timber uniaxial compressions test is different with timber uniaxial tension test. In timber, the mechanical property for tension is different with the mechanical property for compression, both for parallel and perpendicular to the grain. However, the tension mechanical property is always higher than the compression mechanical property. Especially for analytical calculation or numerical simulation, the two mechanical properties (which are compression strength and tension strength) should be obtained. Compression strength property needed for compression member design, while tension strength needed for tension member design.

In this paper, a finite element analysis (FEA) of uniaxial tension of timber, using von Mises Criterion (Chen and Han

2007) to include orthotropic nature of the material, was used to derive a prediction of tensile strength at an angle to the grain (cross grain) in plane stress (2D) situation. To investigate the validity of the finite element analysis results, various 5°, 10°, and 15° cross grain specimens of Yellow Meranti (*Shorea spp.*) were tested under uniaxial tension stress.

Materials and Methods

Wood is generally assumed to behave as an orthotropic material with three mutually perpendicular material principal axes, namely the longitudinal, radial, and tangential axes. The constitutive relation of a linear elastic orthotropic material can be described in accordance with Hooke's law (Persson 2000, Chen and Han 2007).

The elastic modulus (E) is the slope of the stress-strain curve in the elastic region. EL is the slope of the longitudinal-axis (parallel to the grain) stress-strain curve. ER is the slope of the radial-axis stress-strain curve. ET is the slope of the tangential-axis stress-strain curve. In this research, the radial and tangential axes were assumed to be equal and called perpendicular to the grain.

Tensile strength is the strength limit that can be achieved when the timber structure or the timber component failure due to tension, or measures the force required by a timber element/structural element to the point where it breaks.

Numerical simulation to predict the yield stress for compression at an angle to the grain can be done using a software application named ADINA, based on nonlinear finite element analysis (FEA). Nonlinear stress-strain curves for all three principal axes of the orthotropic material are modeled in accordance with Hill's yield criterion. The hardening rule is defined in terms of the relationship between the yield stress and the accumulated effective plastic strain. The three-dimensional solid element is a variable of 10-node isoparametric element applicable to general 3-D analysis. A numerical model of the specimen was modeled using one of the 3-D elements called a tetrahedral element with ten nodes (Bathe 1997, Bathe 2009a, Bathe 2009b).

Results and Discussion

Experimental research was conducted in the laboratory of structure with all sorts of existing equipment (Surono 2013). Specimens were prepared in advance, as well as the direction of the lab assistant on duty. The study was conducted in one day with some specimens of Yellow Meranti wood was formed in such a way as to be easily placed in the test apparatus in accordance with ASTM D143 (ASTM 2008).

There were several steps to conduct this study tensile test timber. Meranti wood tensile testing stages in this study are as follows:

1. Check the size, dimensions, and the water content of the test object manually using a ruler and moisture gauges. Dimensions that are checked include the midpoint of the specimen thickness and angle.
2. Numbering specimens and prepare a data table to record the input and output of data on research. The next pair of LVDT on the stand that has been prepared on the specimen.
3. Mounting the specimen on a Universal Testing Machine. Turning on Universal Testing Machine and wait for the test specimen fractures due to tensile loads generated by the machine.
4. After the specimen was broken, the engine is off and the recording of data in the form of a tensile load is indicated on the monitor.

Figure 1 show the tensile test specimens that was made in accordance with ASTM D143 (ASTM 2008). Figure 2 show the specimen placed on the UTM machine. LVDT are placed in the middle of specimen. Figure 3 show the specimen after tested until failure occurs in the middle tension area.

Figure 1. Numbering the specimens (Surono 2013).

Figure 2. Specimen placed on the UTM (Surono 2013).

Figure 3. Failure mode of some specimens (Surono 2013).

Numerical analysis (finite element analysis or FEA) was done using ADINA Software. Figure 4 show the example of nodal point that was observed in this paper. Figure 5 show the results of finite element analysis for grain angle 5 degree, i.e. the curves of load (in relationship with time) and displacement. Figure 6 show the results of finite element analysis for grain angle 10 degree, i.e. the curves of load (in relationship with time) and displacement. Figure 7 show the results of finite element analysis for grain angle 15 degree, i.e. the curves of load (in relationship with time) and displacement.

Figure 4. Nodal point that was observed (Surono 2013).

Figure 5. Finite element analysis results for grain angle 5 degree (Surono 2013).

Figure 6. Finite element analysis results for grain angle 10 degree (Surono 2013).

Figure 7. Finite element analysis results for grain angle 15 degree (Surono 2013).

On experimental studies specific data obtained from the UTM output. The data is the data load per unit time and the data transfer is then processed into a graph stress - strain relationship of each specimen. The trick was to load the specimen expansion (10 x 10 mm) as the voltage, and the displacement divided by the initial length of the test specimen (100 mm) as a strain. Specimens were tested with a total nine pieces each corner of the specimen consists of three specimens. Specimen number 7, 8, 9, has a grain angle of 5°. Specimen numbers 2, 4, 5 has a grain angle of 10°. Specimen number 1, 3, 6, has a grain angle of 15°. No. 8 specimens failed in the test and will not be discussed further. The following chart load and displacement relationship of experimental research results then converted into the stress - strain relationship curves, using symbols named BU no x, with x is the code of each specimen. Tensile strength of wood to 5° angle is 124.50 MPa (or N/mm²) on average, an angle of 10° is an average of 115.86 MPa, and an angle of 15° is an average of 107.63 Mpa.

After conducting numerical and experimental studies, it can be displayed as a stress - strains a relationship graph, both obtained from experimental tests and numerical analysis (finite element analysis or FEA).

Table 1. Comparison of tensile strength, based on Hankinson equation, FEA and experimental tests (Surono 2013).

Angle (°)	Hankinson (H) $f_{t,\alpha}$ (N/mm ²)	Experimental (E) $f_{t,\alpha}$ (N/mm ²)	FEA (N) $f_{t,\alpha}$ (N/mm ²)	% relative (H) and (E)	% relative (H) and (N)	% relative (E) and (N)
5	105.211	124.50	90	15.49	14.46	27.71
10	86.861	115.86	90	25.03	3.49	22.32
15	67.606	107.63	80	37.19	15.49	25.67

Figure 8. Stress-Strain Curves: FEA and experimental results for grain angle 5 degree (Suroño 2013).

Figure 9. Stress-Strain Curves: FEA and experimental results for grain angle 10 degree (Suroño 2013).

Figure 10. Stress-Strain Curves: FEA and experimental results for grain angle 15 degree (Suroño 2013).

Results can be discussed from this study are:

1. Calculations were performed with the numerical analysis (FEA) and Hankinson method gives results that the difference is not too significant, for specimens with a grain angle of 5° difference in outcomes by 14%, for a grain angle of 10° difference in outcomes by 3%, and for a grain angle 15° difference in outcomes by 15%.
2. Calculations were performed with the Experimental Tests and Hankinson method gives results that the difference is not too significant, for specimens with a

grain angle of 5° difference in outcomes by 15%, for a grain angle of 10° difference in outcomes by 25%, and for a grain angle 15° difference in outcomes by 37%.

3. Calculations were performed with the numerical analysis (FEA) and Experimental Tests gives results that the difference is not too significant, for specimens with a grain angle of 5° difference in outcomes by 27%, for a grain angle of 10° difference in outcomes by 25%, and for a grain angle 15° difference in outcomes by 22%.

Conclusions

Conclusions derived from this study are FEA can be used to test the tensile strength of wood analyze numerically by finite element analysis (FEA). A specimen tilt angle was measured manually at the time of experimental research in progress. The present study uses three kinds of angles, i.e. 5°, 10°, and 15°. The greater the angle of the specimen axis, the lesser the tensile strength was. Comparison with experimental results shows that the FEA simulation predicts the stress-strain curves lower than experimental results, which result shows good agreement, it is seen from %-relative difference which is less than 30%. Based on these results, the FEA is a conservative method for predicting tensile strength at an angle to the grain ranged from 5° to 15°.

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