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DOĞU KAYINI ODUNU BASMA DAVRANIŞININ ÜÇ BOYUTLU SONLU ELEMANLAR ANALIZI

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Özet-Sonlu Elemanlar Metodu malzeme ve sistemlerin dış etkenlere karşı davranışlarının analizinde kullanılan nümerik bir yöntemdir. Bu çalışmada doğu kayını (*Fagus orientalis* L.) odununun basma davranışının üç boyutlu sonlu elemanlar analizi yapılmıştır. Simülasyonu gerçekleştirilen basma örnekleri 20x20x60mm ölçülerde lif, radyal ve teğet yönlerde hazırlanmıştır. Deney örnekleri hazırlanırken düzgün lifli, budaksız ve kusursuz olmasına dikkat edilmiştir. Deney önekleri 20 sıcaklık ve %65 bağıl nem seviyesinde kondisyonlanmıştır. Basma testleri universal test cihazında gerçekleştirilmiş ve bi-aksiyal ekstensometre kullanılarak gerilme deformasyon eğrileri elde edilmiştir. Basma modellerinin sonlu elemanlar analizi üç boyutlu ortotropik malzeme parametreleri kullanılarak gerçekleştirilmiştir. Sonlu elemanlar modellerinden elde edilen deformasyon miktarları ile yük deformasyon eğrileri elde edilmiş ve basma testlerinden elde edilen eğrilerle karşılaştırılmıştır. Oluşturulan üç boyutlu sonlu elemanlar modellerinin gerçek davranışa yakın değerler verdiği ortaya koyulmuştur

Anahtar Kelimeler- Doğu kayını, Sonlu Elemanlar Analizi (SEA), basma

THREE DIMENSIONAL FINITE ELEMENT ANALYSIS OF COMPRESSION BEHAVIOR OF ORIENTAL BEECH

Abstract- Finite Element Method (FEM), is a numeric method which is used to analyze material or systems behavior to external factors. In this study, three dimensional (3D) finite element analyses (FEA) of oriental beech woods' compression behavior was performed. Defect free compression samples, which were simulated, were prepared 20*20*60mm of sizes through longitudinal (L), radial (R) and tangential (T) directions. All the samples were conditioned at 20ºC and 65%RH using conditioning chamber. Compression tests (CT), were performed using Universal Test Machine (UTM) and stress and deformations curves were obtained by bi-axial extensometer. FEA of compression models were performed using 3D orthotropic material properties. Load deformation curves were obtained using deformation values of FE Models and then these were matched against the curves obtained by CT. As a result, it is concluded that created 3D FE Models showed real-like behavior values.

Key Words- Oriental beech, finite element analysis, compression

Bu makale, 4. Uluslararası Mobilya ve Dekorasyon Kongresi'nde sunulmuş ve İleri Teknoloji Bilimleri Dergisi'nde yayınlanmak üzere seçilmiştir.

1.INTRODUCTION

Finite Element Method (FEM) is a numeric method which is used to analyze material or systems. FEM includes numerical solution of mathematical models that express the equalization of force matrix {F} to rigidity matrix {K} and deformation matrix {u} for static structural calculations [1]. FEM is commonly used in lots of engineering field by the virtue of developing technologies. ALGOR™, COSOS/M™, NASTRAN™, ADINA™, ANSYS™, ABAQUS are some of the software that used for Finite Element Analysis (FEA).

In recent years, FEM commonly came into use for analysis of complex structures or systems under dynamic or static conditions [2]. And, according to Mackerle [3] nearly 300 studies concerned with FEA of wood or wooden structures from the years of 1995 to 2004. Topics of these studies varied from the basic properties to structural use of wood.

This method is capable to figure out some properties of three dimensional (3D) stress and strain relation even in hidden parts which static tests can't do. But, it can be said that lack of exactly and fully identified wood material properties inhibited researchers from conducting structural finite element analysis of solid wood at macroscopic level [4]. Using elastic constants of wood through three mutual directions for FEA can prevent some problems that occur due to inhomogeneity and anisotropic structure [5].

Wood is an anisotropic material and its physical and mechanic properties differ according to three mutual directions. And, orthotropic material system is well accepted and most common anisotropy level for wood [6]. Due to this reason orthotropic material properties of wood must be clearly known to perform FEA. For further analysis such as non-linear, lots of material properties such as Young's modulus, Poisson ratios, shear modulus, yield stress values of compression or tension through L, R and T directions are required.

Some researchers modeled wood as linear orthotropic material to perform FEA while others non-linear orthotropic. Mihailescu [7] and Guan and Rodd [8] modeled wood as linear orthotropic material and they sated that model worked well in elastic region. But non-lienar modeling is essential to predict behavior of model from semi plastic region to fracture point. Hong and Barret [9] and Hong et al. [4] performed non-linear FEA using non-linear orthotropic material properties and reported that experimental and FEA results conformed to each other.

Al-Dabbagh et al. [10] presented a theoretical 3D FEM for anisotropic materials such as wood. They discussed feasibility of FEM on compression, tension and torsion problems of wood mechanic. One of the limiting factors of Modeling is that there are lots of parts which have different dimensions. Tabiei and Wu [11] used Japanese ash, katsura and spruce to create 3D nonlinear orthotropic models. It is stated that these models powerfully demonstrated the non-linear characteristic of wood and they suggested a 3D material modeling approach for wood. Gaff et al. [12] performed nonlinear FEA of European beech using SolidWorks software. Stress-strain curves that obtained by bending tests were used to define wood material parameters. They noted that it's possible to determine stress-strain curves without performing static tests under real conditions.

The aim of this study is Finite Element Modeling of 3D compression behavior of beech wood, which is an orthotropic material. Required input parameters for non-linear analysis were obtained by compression test (CT) and 3D FEA performed using these parameters. FEA and static test results were compared to evaluate whether they conformed or not.

2. METHOD

In this study, Oriental beech (*Fagus orientalis* L.) wood used due to its' common use in furniture manufacturing industry in Turkey. Beech trees with straight trunk were harvested from Devrek forest zone in Zonguldak city which located western black sea region of Turkey. Trees diameter was approximately 50cm. Logs were sawn to 25x100mm radial and tangential timber and then 20x20x60mm L, R and T direction compression samples were obtained from these laths as seen in Figure 1. All test samples acclimatized at 20°C temperature and 65%RH condition till their weight became constant and it took around 6 to 8 weeks.

Density of test samples were calculated using stereo-metric method (volume and mass measurements) according to TS 2472 [13] standard. Moisture Content (MC) of test samples were determined according to TS 2471 [14] standard.

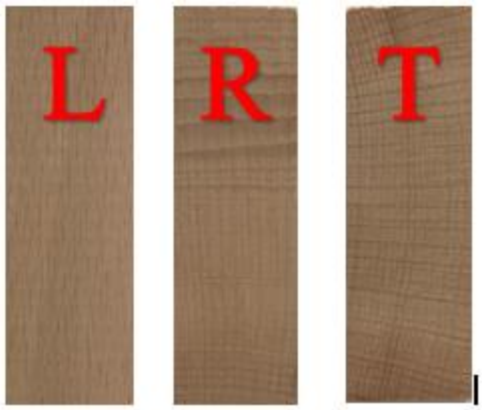

Figure 1. L, R and T Compression test samples.

Compression tests were carried out using 5 ton capacity universal test machine (UTM) with 6mm/min loading speed. Bi-axial extensometer (Figure 2) used to obtained stress-strain curves that are necessary to calculate Young modulus. Elastic regions were determined using stress-strain curves obtained from static tests and Young modulus (of L, R and T directions) determined using formula 1 which uses stress (σ) and strain (ε) values.

$$E_i = \frac{\Delta\sigma_i}{\Delta\varepsilon_i} = \frac{\sigma_{i,2} - \sigma_{i,1}}{\varepsilon_{i,2} - \varepsilon_{i,1}} i \in L, R, T \quad (1)$$

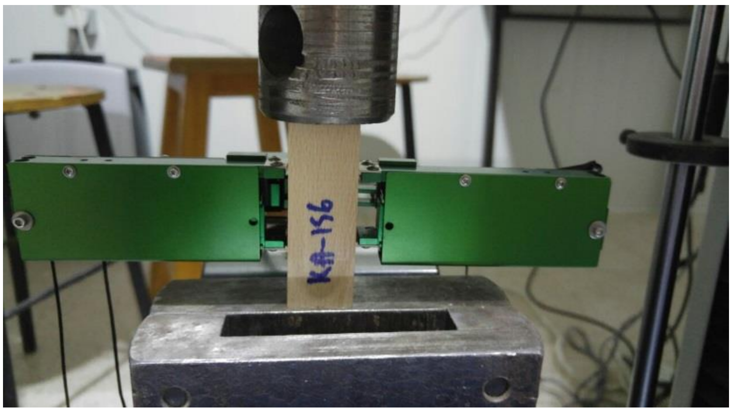

Figure 2. Bi-axial extensometer and compression test configuration.

Poisson ratio is one of the other necessary parameters to model wood material. In this study, Poisson ratios were calculated from the values obtained by compression test. Longitudinal and cross sectional strain values were obtained using bi-axial extensometer under compression test and these values used in formula 2 to calculate Poisson ratios of L, R and T directions.

$$\nu_{ij} = -\frac{\varepsilon_i}{\varepsilon_j}, \quad i, j \in R, L, T \text{ and } i \neq j \tag{2}$$

where;
ε_i , represents the active strain component in the load direction,
ε_j , is the passive (lateral) strain component, which was determined in the linear elastic range from the linear regression of the passive–active strain diagram.

Shear modulus of material is essential for non-linear analysis and these values (G_{LR}, G_{LT}, and G_{RT}) for beech wood were obtained by Guntekin et al. [15] and reported as 1230 N/mm^2, 887 N/mm^2, and 430 N/mm^2 respectively. Reported values used for modeling in this study.

Yield stress values, to perform non-linear 3D FE Modeling, were obtained by transforming of load-deformation curves to stress-strain curves. Stress calculated by ratio between applied force (N) to cross section (mm^2) of test sample.

3D FE model (20x20x60mm) of compression specimens were created using ANSYS software as seen in Figure 3. Solid 45 structural elements used to create CT samples through L, R and T directions. Density, linear orthotropic and multi-linear elastic material properties were defined for non-linear structural analysis. Mesh of whole solid volume or elements refined using second level of refinement. Structural displacement fields and pressure areas of CT specimens selected and parameters defined before running non-linear analysis.

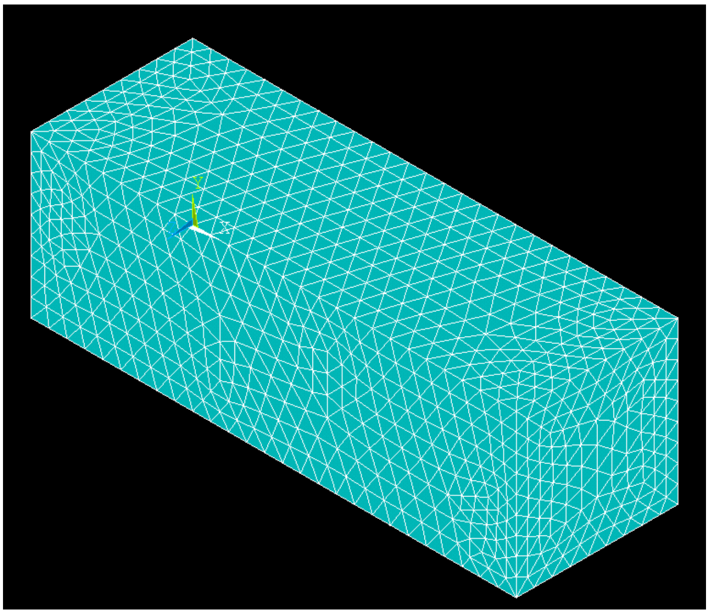

Figure 3. Meshed solid 45 structural element or 20x20x60mm CT sample.

3. FINDINGS

Average density of beech wood calculated as 0.7gr/cm^3. This value well agreed with the study which Efe and Çağatay [16] reported as 0.71g/cm^3. Average MC of the samples was calculated as 12.24%. Required material properties for FEA were not existing in default material library of software and obtained by static CT. These parameters, seen in Table 1, were used for orthotropic material modeling and performing non-linear analysis.

Table 1. Calculated material properties and 3D FE model parameters of beech wood.

Material parameters	*Unit*	*Value*
Elastic modulus (L/R/T)	(N/mm^2)	13047/1829/957
Shear modulus (LR/LT/RT)	(N/mm^2)	1230/887/430
Poisson's ratio (LR/LT/RL/RT/TL/TR)	-	0.539/0.449/0.064/0.565/0.064/0.465
Compression yield stress (L/R/T)	(N/mm^2)	52.10/14.01/7.73
Shear yield stress (LR/LT/RT)	(N/mm^2)	15.96/13.69/6.74

Load-deformation curves of L, R, and T directions that obtained by static compression test were compared with load-deformation curve that obtained by FEA and presented as seen in Figure 4, 5, and 6, respectively. As seen in figures, it can be said that load-deformation curves of L, R, and T directions which obtained by FEA well matched with static ones. Average yield stress values obtained by static compression test were calculated as 52.10N/mm^2, 14.01N/mm^2, and 7.73N/mm^2 for L, R, and T directions, respectively. Average yield stress values obtained by FEA were calculated as 45N/mm^2, 11N/mm^2, and 6N/mm^2 for L, R, and T directions, respectively and it can be said that there were minor differences between them.

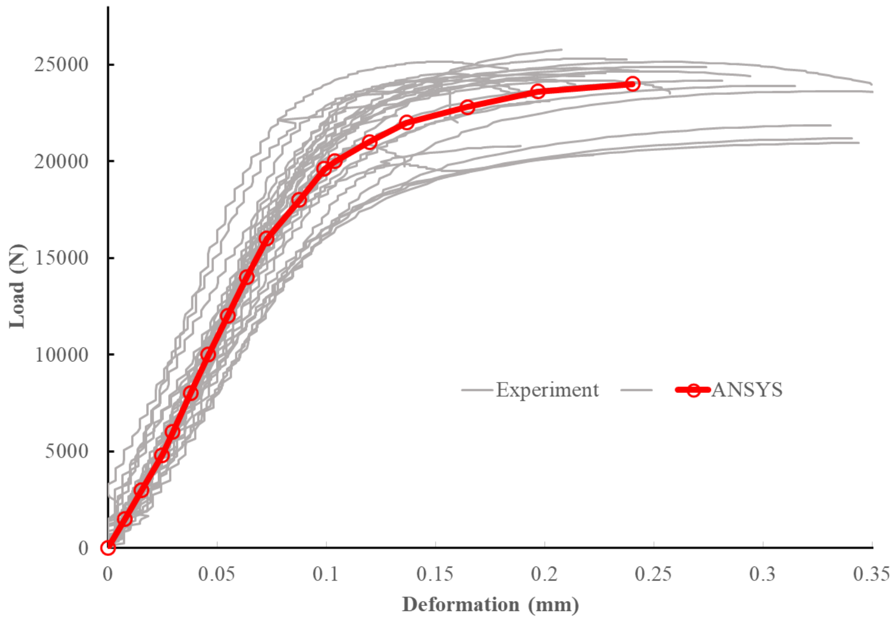

Figure 4. Comparison of load-deformation curves that obtained by CT and FEA through L direction.

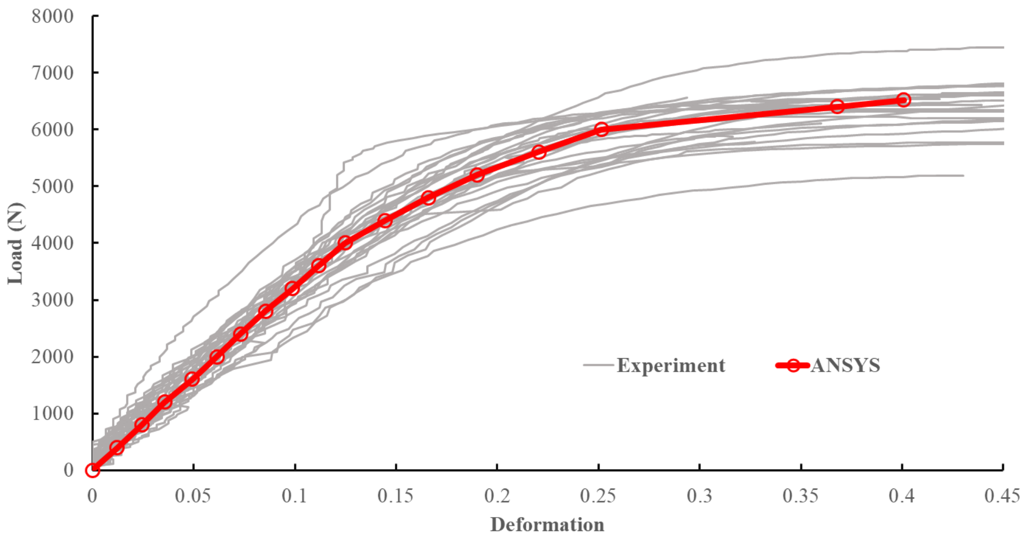

Figure 5. Comparison of load-deformation curves that obtained by CT and FEA through R direction.

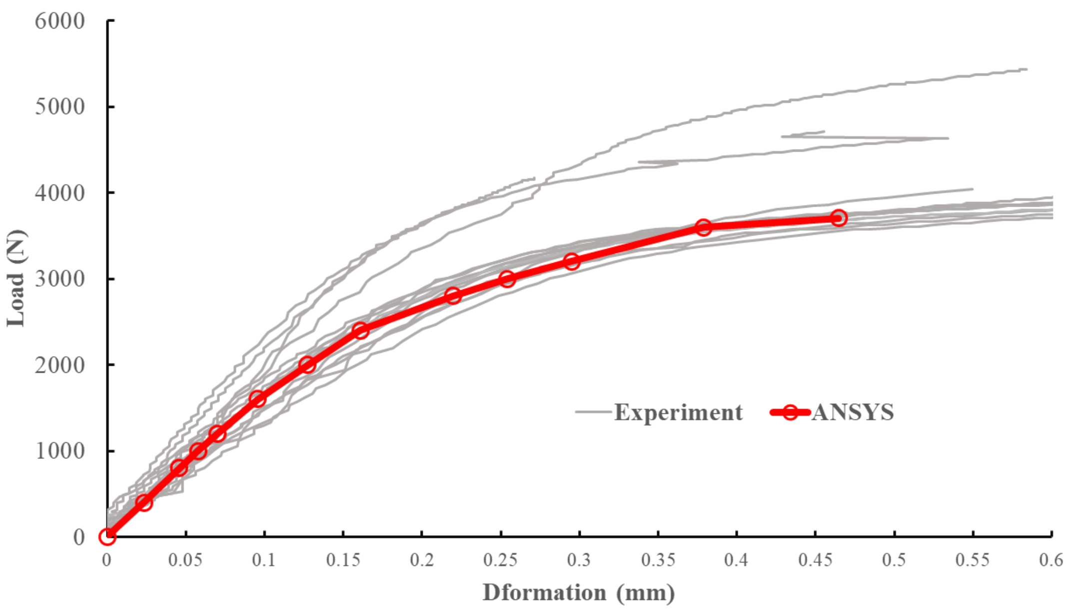

Figure 6. Comparison of load-deformation curves that obtained by CT and FEA through T direction.

FEA graphs (which demonstrate the deformation of element) of models compressed with different pressure values through L, R, and T directions seen in Figure 7, 8, and 9, respectively. And, reasonable deformation values were obtained by FEA for both directions. When load-deformation curves, which created using deformation values obtained by FEA, both elastic and plastic region behavior seems well-matched with static results and proceeded on the same curve. After yield point, plastic deformation of material started and deformation amount rose in plastic region. Elastic behavior can also be seen when material modeled as linear but plastic region behave can only be seen if non-linear analysis performed. Due to this reason, non-linear analysis must be conducted to obtain real-like material behavior. In this study, compression test models created using ANSYS demonstrated non-linear behavior.

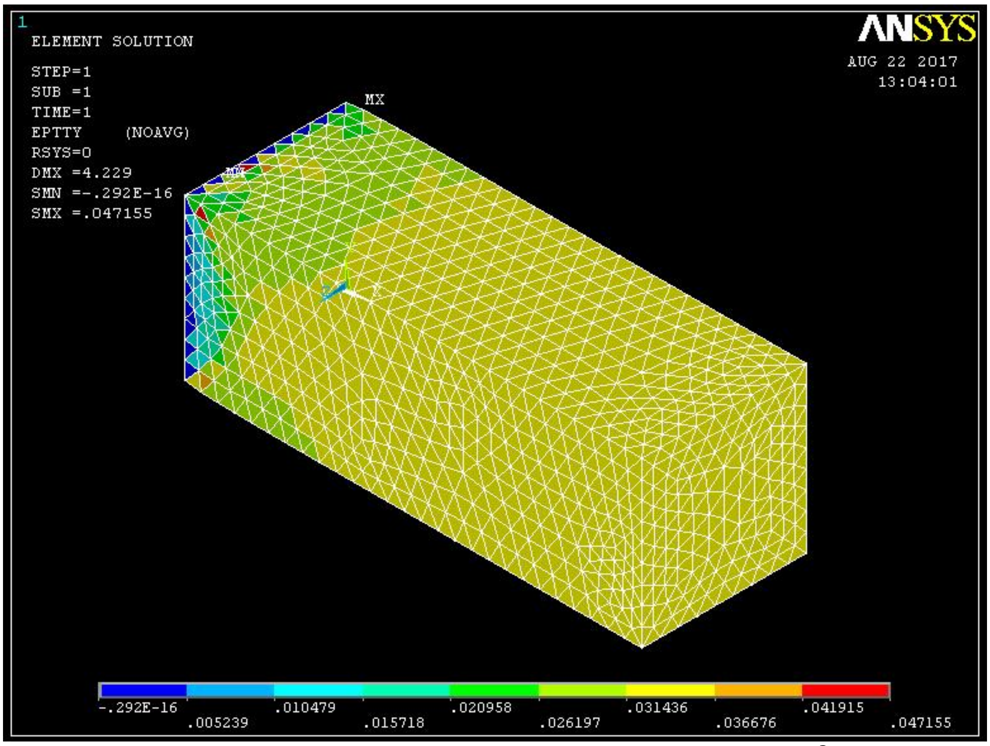

Figure 7. FEA Solution of L compression model under 40 N/mm^2 pressure.

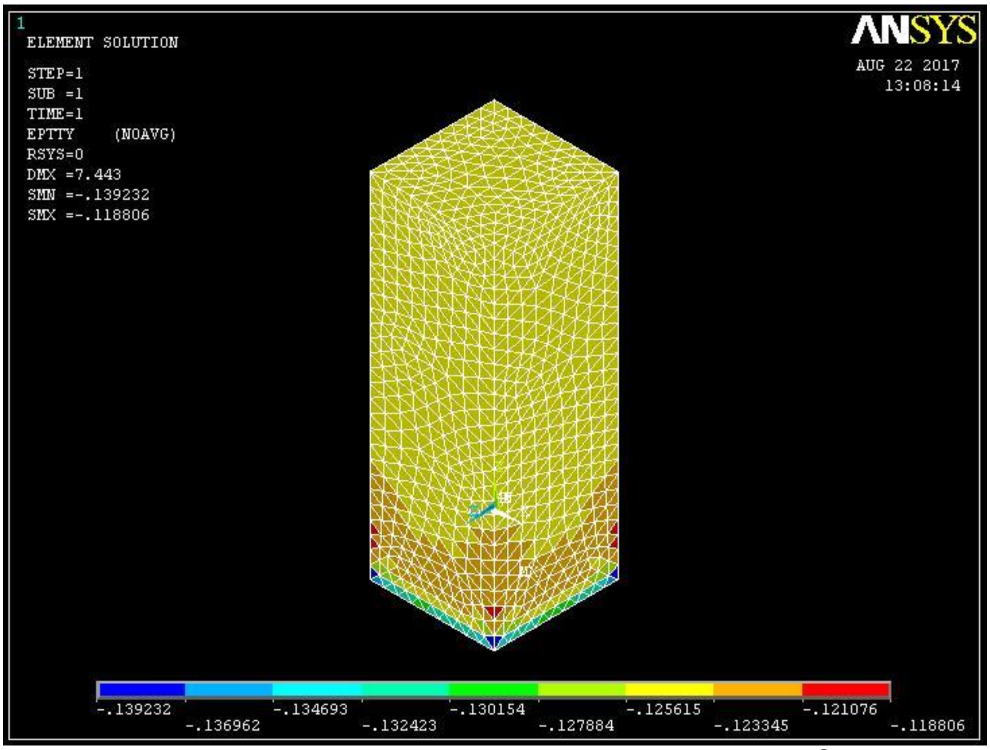

Figure 8. FEA Solution of R compression model under 10 N/mm^2 pressure.

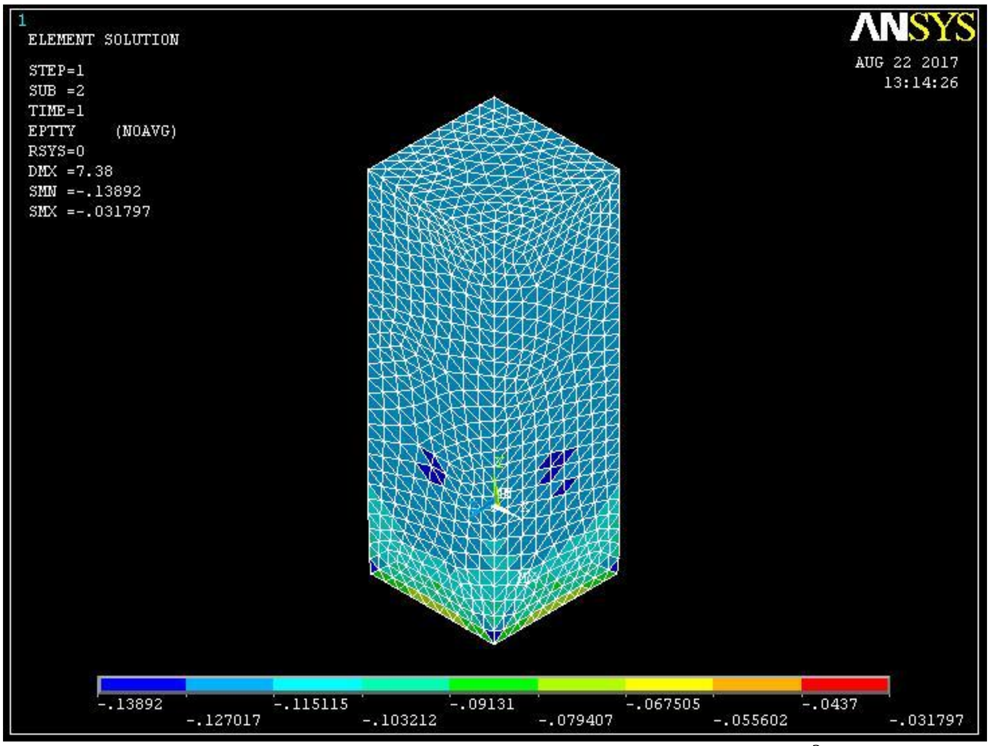

Figure 9. FEA Solution of T compression model under 5 N/mm^2 pressure.

4. CONCULUSION AND DISCUSSION

Modulus of Elasticity values obtained by bending test are used for FE Modeling due to lack of properties of lots of wood species. But these values also contain shear deformation effects or values and it can lead researchers to mischaracterize the material behavior. Young's modulus values (13047 N/mm^2, 1829 N/mm^2, and 957 N/mm^2 for L, R, and T directions, respectively) that obtained by static test used in this study to eliminate this issue. Results demonstrated that these values provided well-matched FEA results. Another important issue is that poisons ratios of lots of wood species still undetermined. In general these ratios are derived from the literature considering the soft and hardwood species or 0.3 value is used to perform FEA.

FE Method provides some advantages to users such as obtaining real-like results, saving on time, and economic contributions. Predicting material or structure behavior by the help of FEA at the beginning (at design phase) ensure safer and durable structures and reduces the costs. This is one of the important approaches for engineering design activity.

In general, default material library of Computer Aided Engineering (CAE) software do not completely include full material properties (especially wood species properties) to perform not only linear analysis but also non-linear. There are lots of factors such as climate, elevation, exposure, region that alter the properties of wood material even if it's the same species. And, it can be said that there are lots of species still not fully characterized. This study provides some of these values for beech wood to perform non-linear analysis.

In this study, three dimensional compression behavior of beech wood evaluated using FE Method. Models created and analyzed using ANSYS software. FEA and experimental results demonstrated well agreement on compression behavior of beech wood.

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