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MECHANICAL BEHAVIOR OF WOOD UNDER TORSIONAL AND TENSILE LOADINGS

Ezgi GÜNAY*
Gazi University, Faculty of Eng. and Arch., Mechanical Eng. Dept., 06570, Ankara, TURKEY, egunay@gazi.edu.tr
Murat SÖNMEZ
Middle East Technical University, Technical Vocational School of Higher Education, 06531, Ankara, TURKEY

ABSTRACT

Wood and wood products are among important construction materials. More recently, designers have learned to design wood structures in ways that are based on engineering principles. In doing this, a structural designer must be familiar with the properties and behavior of the material. The properties and behavior of wood are unlike those for other materials and much more complex by considering their organic structure. In this study, torsion and tensile tests were performed in order to examine the mechanical behaviors of Turkish beech, pine and oak woods. In doing this, wood is considered as a transversely isotropic fiber composite material. The stress-strain curves were constituted and examined in order to show the elastic and plastic regions, the yield points if they are exist and additionally fiber composite elastic material constants of them. They were determined within the approximate error ranges. At the end of the research, stress relaxation tests were applied on both pine and beech woods under torsion loadings.

Key Words: Wood, torsion and tensile tests, mechanical properties, fiber composite, transversely isotropic, elastic-plastic regions, hysteresis loop, stress relaxation test

BURULMA VE ÇEKME YÜKLEMELERİ ALTINDA AĞACIN MEKANİK DAVRANIŞLARI

ÖZET

Ağaç ve ağaç ürünleri önemli yapı malzemeleri arasında bulunmaktadır. Günümüzde, tasarımcılar ağaç yapı tasarımlarını, mühendislik prensipleri içerisinde gerçekleştirmeyi öğrendiler. Böylece, yapısal tasarımcılar kullandıkları malzemelerin özelliklerini ve davranışlarını bilmek zorundadırlar. Ağacın özellikleri ve davranışları, onların organik yapılarını dikkate aldığımızda, diğer malzemelerden oldukça farklı ve karmaşıktır. Bu çalışmada, çekme ve burulma deneyleri, Türkiyedeki kayın, çam ve meşe ağaçlarının mekanik davranışlarını incelemek için yapılmıştır. Çalışma sırasında ağaç, yanal ortotropik fiber yapılı kompozit olarak değerlendirilmiştir. Gerilme-genleme grafikleri, eğer varsa elastik ve plastik bölgeleri, akma noktalarını ve ek olarak fiber kompozit elastik malzeme sabitlerini bulmak için oluşturularak incelenmiştir. Sonuçlar yaklaşık hata oranları arasında elde edilmiştir. Araştırmanın sonunda ise, gerilme boşalması testleri çam ve kayın ağaçlarının üzerinde burulma yüklemesi altında test edilmiştir.

Anahtar Kelimeler : Ağaç, burulma ve çekme deneyleri, mekanik özellikler, fiber kompozit, yanal izotropik, elastik-plastik bölgeler, tekrarlanan yüklemeler, gerilme boşalması testi

1.INTRODUCTION

Wood and wood products are among important construction materials. Wood and cellulose fibers are generally used in frames, truss roof structures in buildings, automotive components, shipping crates and pallets, storage bins and seasonal furniture. Over the centuries, man learned to use wood effectively, developing rules of thumb to aid in building wood structures. These rules were based only on experience. More recently, however, engineers and architects have learned to design wood structures in ways that are based on engineering principles. Thus today's designers, using design procedures, are able to ensure that a particular design will achieve the desired level of structural safety and stiffness as well as economy(1). Much progress has been made in moving from rule-of-thumb design to present-day engineering designs. To design effectively, a structural designer must be familiar with the properties and behavior of the material. Wood is a natural material. It is known as an orthotropic type fiber composite organic structure in general and the determination of its mechanical characteristic behaviors is attracting attention. Unfortunately, the properties and behavior of wood are unlike those for other common building materials and much more complex. Same type of trees which are growing up at different localities, generally may support dissimilar mechanical material properties under tensile and torsional load types. Consequently, the engineering properties of wood are extremely variable naturally. It is hoped that by means of selective tree farming, straighter and faster-growing trees may be developed with more nearly uniform properties than are found in trees from natural forests. Mechanical properties of wood, determined from small, nearly perfect wood specimens become the bases for the allowable stresses given by design codes. The strength and stiffness properties of wood which are of interest in the structural design problems may be given as compressive strength parallel to the grains, compressive strength perpendicular to the grains, tensile strength parallel to the grains, modulus of elasticity parallel to the grains, modulus of rupture, longitudinal shear strength, and the shear modulus. In this study, torsion and tensile tests were performed in order to examine the mechanical behaviors of beech, pine and oak woods. The stress-strain curves were constituted in order to show the elastic, plastic regions, the yield points and elastic material constants. The main procedures of the experimental studies in this article include the applications of cyclic and non-cyclic torsional loadings of pine wood, beech wood specimens and tensile loading applications on oak, beech and pine wood specimens. Nowadays the studies on woods in terms of cyclic loading, torsional loading for the determination of shear modulus of woods are rarely seen. Because, it is difficult to obtain the same experimental results from the each experiment. The laboratory temperature and moisture conditions are effecting the results under the consideration of composite material testing. The torsional loading gives the cross sectional surfaces of the bars a non uniform shear stress distribution because of the transversely isotropic layered composite property. Here, it is also important to note that testing a small clear specimen takes only a few minutes, but in service wood will be under load for a much longer time. Since the length of time that a load is present on a wood member affects the ultimate strength of that member, the designer of wood structures must consider that effect. In order to consider the load-duration effect, it is advised to divide the strength values by a factor given in Fig.1 obtained from the test results. This graph is the result of the research by the Forest Products Laboratory (2).

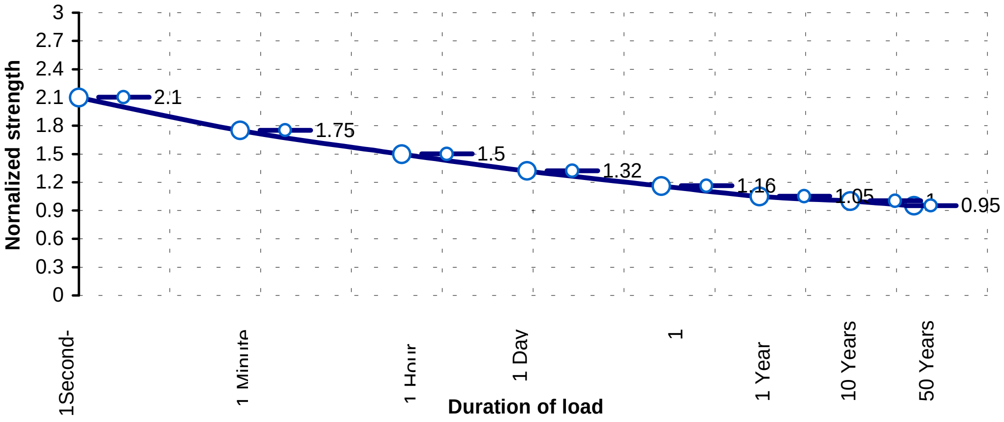

Figure 1. Effect of load duration on strength of wood (Courtesy Board of Regents, University of Colorado)

Because of the complexity of the wood structure and variability of types, there is little scientific literature about the declarations of mechanical behavior of woods. Especially, torsional rigidity of the woods can be seen in the literature seldom as it is mentioned. Hayashi, et al.(3) studied wood specimens by coducting tensile tests. In his study, viscoelastic compliance terms were obtained through the radial direction at 21°C and 12% equilibrium moisture content. The time dependent strain reduced the ultimate strength by 58%. The compliances were represented by time power functions. Woodward and Minor(4) examined Douglas-fir timbers for the determination and comparison of the failure formulas. For the six-grain angles 0°, 15°, 30°, 45°, 60°, 90°, Douglas-fir wood was examined. The study took the stress-strain hysteresis loop and yield surface into consideration. In 1979, J.J Mack(5) introduced the Australian standard test methods among the other common test methods (the British method (ASTM method of testing (6)) for small clear specimens of timber. He considered the test methods for static bending, compression parallel to the grain, compression perpendicular to the grain, hardness, impact and torsion tests. Mack used solid test specimens(5) with cylindrical central part. This research paper is one of the rare ones which gives the wood specimen geometrical parameters for the tensile/torsional/three point bending tests. Even though it is not a standard practice to use a tubular test specimen in the torsion tests of metals, researches for the tubular wood torsion tests are investigated but there is not any common application to use hollow wood members in structures and there was no reference for torsion test in any available standards which gives the diameter of the hollow part regarding the size and direction of the grains and cells. Yamasaki and Sasaki(7),(8) studied the failure behavior of Japanese beech wood under combined axial force and torque in order to check the failure behavior of wood for grain angles $-90^{o}<\theta<90^{o}$. In this research, the tests were performed by considering test methods given in Turkish Standards (9,10,11,12), Australian methods, and also ASTM standards(6,13).

2. METHODOLOGY

2.1 Selected Tests

The main procedure of the experimental studies in this article includes cyclic and non-cyclic torsional loadings on small clear specimens of beech and pine, and tensile loading on oak, beech and pine specimens with small cylindrical wood bars and rectangular cross sectional specimens. By the help of these studies, the general characteristics of stress-strain curves of woods are determined. The superposition principle can be used in order to illustrate the general behavior of pine and beechwoods under torsion and tensile loadings in linear elastic region. Young's modulus values of St37 steel and aluminum type metals and woods were compared in the specific tensile test experimental procedures in detail. All of the experiments were done under the same laboratory conditions at ~20 ºC. The longitudinal axes of wood specimens were parallel to the grains. In general, tests were bunched in three groups. Each group of test was organized separately and then the results are combined and discussed for the same type of materials. The shape and dimensions of the test specimens are summarized as follows:

- Torsion tests on the beech and pine specimens. The shape of the specimens used in torsion tests is given in Fig. 2. To test whether shear modulus is affected with the changing values of the specimen or not, three different diameters were chosen. They are 6.50mm, 10.0 mm and 12.5 mm. Here it should be mentioned that, due to the shortcomings of the test setup, the maximum diameter was taken less than the given value in Australian method. Total length of the specimen, L was taken as 150 mm. No matter what the diameter is, the same gage length, L_g (= 90 mm) was considered. A and H are the dimensions of the grips of the specimen. H values were taken as 13 mm, 20 mm and 25 mm for the diameters given above, respectively. The length of the grips was taken as 30 mm.

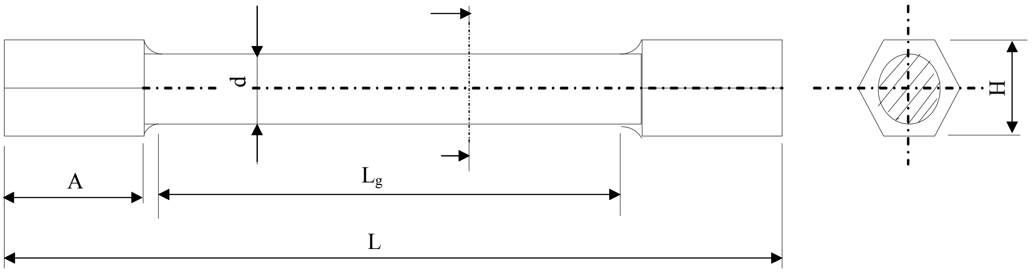

Figure 2. General dimensional configuration of torsion test specimen

- Tensile tests on the oak, beech and pine specimens with a cylindrical central part, (Fig. 3). The characteristic dimensions of the specimens used in this test are given in Table 3. In this table, d_i and d_f are the initial and final diameters of the gage part of the specimen. The initial and final values of the gage length are given with symbols $L_{g\,l}$ and $L_{g\,f}$, respectively. D_0, the diameter of the grips was taken as 16.7 mm with a length of A=50 mm.

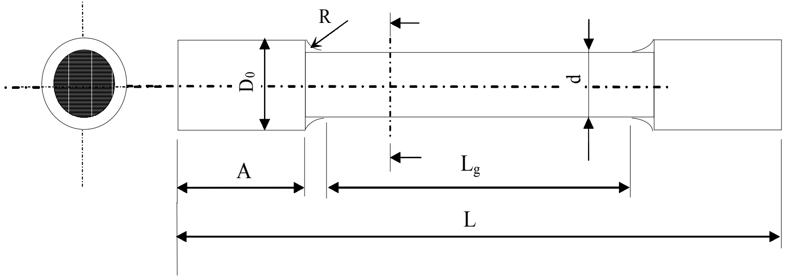

Figure 3. General specification of round tensile test specimen and its orthogonal coordinate representation

- Tensile tests on beech, pine and steel specimens with rectangular cross-sections, (Fig.4). The specimens had L_t=300 mm of total length and a=10 mm of thickness. The height of the gage part was 30 mm. The dimensions of the grips, A and B were 70 mm and 40 mm respectively. Radius of the transition parts between the grips and the gage part was 35mm. With these dimensions the geometry of the specimens are in accordance with TS 2475 [11].

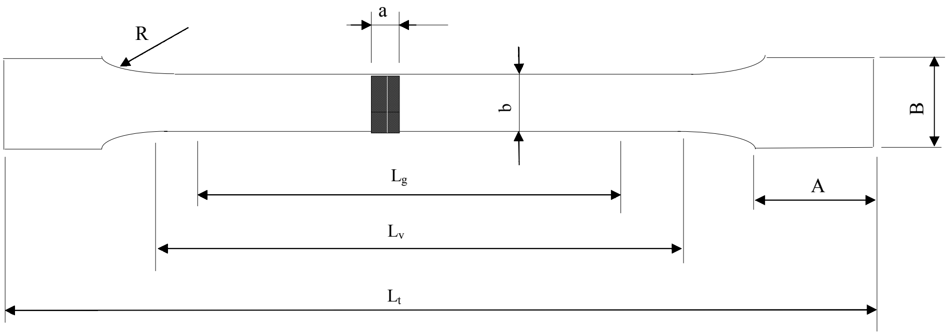

Figure 4. Tensile test specimen with rectangular cross-section

2.2 Laboratory Testing

2.2.1.Torsion Tests

Torsion tests were performed starting from zero value of torque till the value was reached to the one which causes the failure of the specimen by using the torsion-testing machine TQ SM21, which has a driving system having a variable-speed electric motor and a transmission part with a 1:6000 speed reduction ratio(14,15,16,17). In this procedure, torsional load is applied at constant strain rates at two stages. The specimen is loaded to a slow strain rate during the first stage, until yielding occurs, and then, the motor speed is increased to a greater value. The test machine has a digital counter. Via this counter, it is possible to measure angle of twist with an increment of 0.3^{o} .

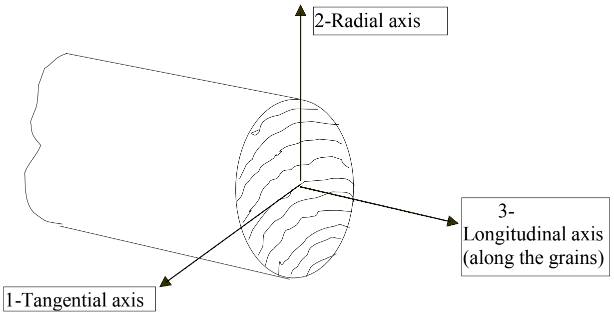

Figure 5. Orthogonal coordinate system of the transversely isotropic wood specimen

Each angle of twist value ϕ^{m} , was transformed to $\gamma_{32}{}^{m}$, which is called the maximum shear strain through the 1st and the 2nd orthogonal coordinate axes of the cross-section. Axes 1, 2 and 3 represent the corresponding orthogonal coordinate system, which 1-2 principal axis are in the plane of the cross-section and the origin of the system is attached to the centroid of this coordinate system through the third principal axis 3 (Fig.5). The well-known stress-strain relationships are;

$$\gamma_{32}{}^{m} = \frac{\tau_{32}{}^{m}}{G_{32}} = \frac{c\ \ \phi^{m}}{L_g} \tag*{[1]}$$

$$\tau_{32}{}^{m} = \frac{T\ \ c}{J} = \frac{2\ \ T}{\pi\ \ c^{3}} \tag*{[2]}$$

Here c is the maximum radial dimension of the radius, $\tau_{32}{}^{m}$ is the maximum shear stress developing in the 1-2 plane, G_{32} is the shear modulus, T is the applied torque by the test-machine, J is the polar moment of inertia of the cross section. In the following sections, $\tau_{32}{}^{m}$ versus $\gamma_{32}{}^{m}$

graphics represent both the linear elastic and plastic regions of the woods. Figures 6, 7 and 8 show the curves for beech and pine. When the graphics are examined, we can see that there is not any definite transition region between the elastic and plastic regions. In order to clarify the shear yield stress regions for both pine and beech approximately, the hysteresis tests were performed. Torsional cyclic loading and unloading were applied on the pine and beech specimens to determine the linear-elastic and plastic regions (Figures 9,10 and 11). In addition to these tests, the stress relaxation tests were applied on both pine and beech while the specimens were held at the applied maximum shear stress levels just before failure. During the stress relaxation tests, the available maximum torque values were applied to the specimens and then the loading was stopped at this level. The torque-meter was read at some definite time intervals.

2.2.2.Tensile Tests

The specimens with cylindrical and rectangular prismatic gage parts (Figures 3 and 4) were tested applying extensometer controlled proof type test procedure by using DARTEC- Tensile Test Machine(16,17,18). Geometric parameters are tabulated in Tables 3-8 corresponding to the experiment numbers and the test results. Proof tests are in three main steps: i) the load is applied to the test piece to set a specified preload stress level ,then ii) extensometer control is activated so that during loading stressing rate can not exceed the maximum rate defined in the standard, up to the preset strain level, (when the preset strain level is exceeded, the test pauses in order to remove the extensometer), iii) the test continues in stroke control, at a rate which will not exceed the maximum straining rate defined by the standard failure of the test specimen happens. The "stress rate" chosen for these tests was the minimum one as 5.00 [N/mm^2]/s in the elastic regions, and the strain rates were 1) $0.00050/\mathrm{s}$ for the first plastic regions, 2) $0.00055/\mathrm{s}$ for the second plastic regions, 3) $0.00057/\mathrm{s}$ for the third plastic regions. The changing diameters of round type wood specimens were measured instantaneously, with the help of extensometer control facility of the hydraulic DARTEC-tensile test machine in order to determine the new fiber composite elastic constants $\eta_{i,ij}$ and $\eta_{ij,i}$. They are called as Lekhnitski's coefficients(19). In literature, in the consideration of experimental studies on wood type specimens there is not sufficient knowledge for the determination of these constants. $\eta_{ij,i}$ denotes the characteristic of the material due to shearing in ij -plane caused by the normal stress in the i^{th} direction. The corresponding equations are;

$$\eta_{ij,i} = \frac{\gamma_{ij}}{\varepsilon_i} \qquad \eta_{i,ij} = \frac{1}{\eta_{ij,i}} \qquad [3]$$

Tables 4,5,6 and 7 include the influence coefficients determined by the experiments related with these wood materials. Related compliance terms of the generally orthotropic structures in plane stress problems are summarized in the Appendix A.

3. RESULTS and COMPARISONS

In this study, three types of wood were examined by applying torsion and tensile tests. The following results were obtained;

1) Shear modulus values of Turkish pine and beech obtained from the torsional tests performed in this study are summarized in Table 1.

Table 1. Shear modulus values of Turkish pine from torsional experiments

Test group number	Diameter d (mm)	Pine G_{12} (GPa)	Beech G_{12} (GPa)
1	6.5	1.76	6.76
2	12.5	-	4.48
3	12.5	-	5.44
4	12.5	1.72	-
5	12.5	2.87	-
5	12.5	1.72	-
6	10.0	1.14	4.03

Torsion tests give the average shear modulus value, for pine $G^{pine}{}_{avg} \approx 1.84$ GPa and for beech $G^{beech}{}_{avg} \approx 2.53$ GPa. Briefly, corresponding shear moduli are found between $1.14 < G_{12}{}^{pine} < 2.87$ GPa and $4.03 < G_{12} < 6.76$ GPa. The maximum shear strains of pine and beech are less than 0.1 rad. Beech reaches to a yield shear stress of $\tau_{32_Y} = 5.32$ MPa while the pine specimen reaches to $\tau_{32_Y} = 4.2$ MPa under torsion loading. Table 2. summarizes the mechanical constants available in the literature for typical woods. Figures 6, 7 and 8 show the $\tau - \gamma$ curves for beech and pine. When the graphics are examined, we can see that there is not any definite transition region between the elastic and plastic regions. In order to clarify the shear yield stress regions for both pine and beech approximately, the hysteresis tests were performed. The torsional cyclic loading and unloading were applied on the pine and beech specimens to determine the linear-elastic and plastic regions (Figures 8,10,11 and 12). Figure 11. plots the $\tau_{32} - \gamma_{32}$ shear stress-shear strain hysteresis curve of the Turkish beech wood under cyclic torsional loading on positive forward direction. Here, the specimen has the radius $r = 6.25$ mm . Figure 12. plots the $\tau_{32} - \gamma_{32}$ shear stress-shear strain distribution of the Turkish pine wood under hysteresial torsional loading by the same radial dimension. From these curves, approximate yield shear stress values can be seen clearly. The hysteresis curves due to torsional loading were determined within the elastic and than plastic regions of the wood specimens. There is not any literature including the hysteresis curves for woods. From the - graphics, it can be seen that sudden decrease in the shear stress occurs after the maximum shear stress value is reached. After this point, fluctuations of stress-strain curves are also seen clearly. This is because; the grains or the fibers of the wood are failing throughout the final seconds of the test by parts group by group.

Table 2. Elastic mechanical properties of some wood types from literature (20), (21), (22), (23)

Wood type	E_3 (GPa)	$\frac{E_3}{E_2}$	$_{32}$	$\frac{E_3}{G_{32}}$	$_T$ * (Elastic Tensile Strength) (MPa)	$_C$ * (Elastic Compressive Strength) (MPa)	$_{uT}$ * (Ultimate Tensile Strength) (MPa)	$_{uC}$ * (Ultimate Compressive Strength) (MPa)	$_{32}$ (MPa)
Balsa	**0.83**	**20.0**	**0.30**	**29.0**	-	-	-	-	-
Pine	**9.81, 10.34, 13.1**	**23.8**	**0.24**	**13.3**	-	-	-	-	**7.6**
Plywood	**11.8**	**2.0**	**0.07**	**17.1**	-	-	-	-	-
Douglas fir, green	**11.0**	-	-	-	**33**	**23**	-	**27**	**6.2**
Douglas fir, air dry	**13.0 –13.1**	-	**.21**	-	**56**	**44**	**100**	**26-51**	**6.2-7.6**
Red oak, green	**10.0**	-	-	-	**30**	**18**	-	**24**	**8.3**
Red oak, air dry	**12.0**	-	-	-	**58**	**32**	-	**48**	**12.4**
White spruce	**9.65**	-	**0.31**	-	-	-		**36**	**6.7**

* Measured parallel to grain.

Therefore, applying the torque with slow strain rates, the gradually failing of fibers can be seen clearly. Additionally, the stress relaxation tests were applied on both pine and beech while the specimens were held at the applied maximum shear stress levels reached just before failure. The stress (torque) relaxation test data are given in Figures 13. and 14. As it can be seen from Figure 12., pine specimen relaxed from ≈ 3.4N.m to a constant torque value ≈ 1.8N.m during 10.000 minutes. Beech specimen on the other hand, relaxed from ≈ 7.8N.m to a torque value ≈ 2.3N.m along 11.000 minutes (Figure 13.). From the data we can say that pine has less creep compliance than beech. It is also seen from Figure 13. and Figure 14. that the torque relaxation curves are obeying the Maxwell's model.

2) Tensile test results are given in Tables 3, 4, 5, 6 and 7 for the specimens with the shape shown in Figure 3. Table 8 represents the results for the ones being in rectangular cross-section (Figure 4). In Tables 3. and 8., F_u , σ_u , σ_{Y_u} and σ_{Y_l} denote the maximum tensile force, tensile strength, upper yield limit and lower yield limit values, respectively. From the data given in Table 3., it can be calculated that, the mean value of σ_u is 62.13 MPa (SD, standard deviation=12.62) for oak, 32.0 MPa (SD=3.16) for pine, and 67.18 (SD=21.7) for beech. The mean value of Young's modulus is obtained as 13.59 GPa (SD=2.56) and 14.16 GPa (SD=4.42), for oak and beech, respectively. Table 8. gives the typical output data determined from tensile tests. The specimens with rectangular cross-section had a sectional area being two times larger than that of the round specimens. This explains why there is a relation between the failure loads as .

Table 3. Tensile test results for the determination of mechanical elastic properties of the Turkish woods

Exp. No	**Wood type**	d_i (mm)	d_f (mm)	d (mm)	L_{gi} (mm)	L_{gf} (mm)	**L** (mm)	**F_u (kN)**	u **(MPa)**	**Young's Modulus (From Graphs)** E_{33} **(GPa)**	**Poisson's Ratio** 31
1	Oak	13.00	12.95	0.05	96.00	99.40	3.4	7.40	56	13.46	0.1089
2	Oak	13.00	12.87	0.13	96.00	98.60	2.6	9.20	69	11.16	0.369
3	Oak	12.80	12.76	0.04	96.00	98.00	2.0	7.30	57	11.60	0.150
4	Oak	12.90	12.86	0.04	96.00	96.00	0.0	7.50	58	11.00	-
5	Oak	13.00	12.80	0.15	94.00	97.60	3.6	6.50	49	16.00	0.300
6	Oak	13.11	13.11	0.00	95.00	95.00	0.0	9.80	72	12.00	-
23	Oak	13.00	-	-	96.00	96.00	-	11.4	86	17.50	-
24	Oak	13.00	-	-	96.00	96.00	-	6.60	50	16.00	-
9	Pine	13.18	13.18	0.00	99.80	105.0	6.2	-	-	-	-
10	Pine	12.96	12.96	0.00	98.80	102.6	2.8	3.90	29	-	-
11	Pine	13.05	12.98	0.07	97.00	99.00	2.0	4.30	33	1.140	0.260
16	Pine	13.19	13.17	0.02	96.60	98.00	0.6	4.90	36	8.820	0.244
17	Pine	13.35	13.26	0.09	95.50	97.00	1.5	4.20	30	5.180	0.429
7	Beech	13.30	13.28	0.02	97.60	97.60	0.0	6.30	46	10.00	-
8	Beech	13.42.	13.40	0.02	100.0	103.0	3.0	14.2	101	18.4	0.0496
12	Beech	12.99	12.97	0.02	96.20	97.00	0.8	6.90	52	7.860	0.185
13	Beech	13.08	13.05	0.03	99.40	100.0	0.6	8.20	61	14.00	0.379
14	Beech	12.95	-	-	100.0	103.0	3.0	12.4	94	-	-
15	Beech	12.64	12.60	0.04	100.0	101.0	1.0	5.70	46	16.00	0.3164
18	Beech	13.47	13.38	0.09	101.4	101.6	0.2	11.2	79	14.67	-
19	Beech	13.45	13.42	0.03	98.40	98.70	0.3	6.00	42	10.70	0.2438
20	Beech	13.44	13.42	0.02	98.40	98.80	0.4	13.3	94	20.00	0.36
21	Beech	13.51	13.40	0.011	98.00	103.0	5.0	10.0	70	20.00	0.16
22	Beech	13.43	13.37	0.06	97.00	98.20	1.2	7.70	54	10.00	0.36

Table 4. Reduction of diameter during Experiment 6. for oak/horn beech specimen

L_0 (mm)	d_i (mm)	A **(mm^2)**	F_i (kN)	**(True Stress) (N/ mm^2)**	$_{ij,i}$	$_{i}$	$_{ij,i}$
97.6	13.30	138.929	-	-	-	-	-
	13.29	138.720	4.14	29.80	0.000752	0.02254	0.03336
	13.27	138.303	6.3	45.55	0.002250	0.07889	0.02859
	13.28	138.511	Failure	-	-	-	-

Table 5. Reduction of the diameter during Experiment 7. for beech specimen

L_0 (mm)	d_i (mm)	A **(mm^2)**	F_i (kN)	**(True Stress) (N/ mm^2)**	$_{ij,i}$	$_{i}$	$_{ij,i}$
97.6	13.30	138.929	-	-	-	-	-
	13.29	138.720	4.14	29.80	0.000752	0.02254	0.03336
	13.27	138.303	6.3	45.55	0.002250	0.07889	0.02859
	13.28	138.511	Failure	-	-	-	-

Table 6. Reduction of radius during Experiment 11. for pine specimen

L_0 (mm)	d_i (mm)	A **(mm^2)**	F_i (kN)	**(True Stress) (N/ mm^2)**	$_{ij,i}$	$_{i}$	$_{ij,i}$
97.0	13.05	133.755	1.92	14.355	-	-	-
	13.02	133.141	2.95	22.157	0.002298	0.03608	0.06369
	13.01	132.936	3.04	22.868	0.003065	0.04000	0.07662
	13.00	132.732	3.50	26.369	0.003831	0.07731	0.04955
	12.97	132.120	3.60	27.278	0.006130	0.08041	0.07623
	12.97	132.120	3.78	28.610	0.006130	0.09794	0.06259
	12.97	132.120	3.80	28.760	0.006130	0.09900	0.06191
	12.96	131.916	4.00	30.322	0.006896	0.10824	0.06371
	12.98	132.324	4.30	32.496	0.005364	0.11340	0.04730
			Gross failure				

Table 7. Reduction of the diameter during Experiment 12. for beech specimen

L_0 **(mm)**	d_i **(mm)**	A **(mm^2)**	F_i (kN)	**(True Stress) (N/ mm^2)**	$_{ij,i}$	$_{i}$	$_{ij,i}$
96.2	12.99	132.528	-	-	-	-	-
	12.99	132.528	2.20	16.60	0.001539	0.0395	0.03896
	12.97	132.120	3.75	28.38	0.001539	0.04677	0.03290
	12.97	132.120	4.12	31.18	0.001539	0.06860	0.02243
	12.97	132.120	5.00	37.84	0.0023095	0.08627	0.02776
	12.96	131.916	5.49	41.62	0.0023095	0.09875	0.02425
	12.96	131.916	5.91	44.80	0.0023095	0.10395	0.02304
	12.96	131.916	6.16	46.69	0.0023095	0.1195	0.02000
	12.96	131.916	6.45	48.89	0.0023095	0.1268	0.01888
	12.93	131.306	6.94	52.85	0.0046189	-	-
	12.93	131.306	7.32	55.75	0.0046189	-	-
	12.92	131.1036	7.85	59.88	0.005388	-	-
	12.92	131.1036	6.90	52.63	0.005388	-	-
	12.97	131.1200	Gross failure				

Table 8. Geometrical and mechanical properties of rectangular cross sectional specimens

Exper. No	**Specimen Material**	L_0 **(mm)**	L_f **(mm)**	**L (mm)**	**Young's Modulus (From the Graphics)** E **(GPa)**	**Fm (kN)**	u **(MPa)**	Y_u **(MPa)**	Y_l **(MPa)**
42	Pine	160	165.0	5.00	16.80	12.70	25.	-	-
53	Pine	130	132.0	2.00	19.80	23.77	77	38	36
54	Pine	130	135.0	5.00	17.00	16.30	53	-	-
57	Pine	140	155.8	15.8	21.50	25.60	83	70	60
58	Pine	140	147.0	7.00	17.50	17.20	55	-	-
62	Pine	140	149.0	9.00	16.10	25.10	81	-	-
51	Beech	130	133.0	3.00	16.20	23.60	76	61	58
52	Beech	130	134.0	4.00	15.00	28.70	93	85	74
55	Beech	130	133.7	3.70	12.70	18.90	61	-	-
56	Beech	130	135.0	5.00	19.60	35.00	113	-	-
61	Beech	140	150.0	10.0	14.70	15.00	49	-	-

3) $\eta_{ij,i}$ Lekhnitski's coefficient calculated using the data obtained from experiments 6,7,11 and 12 are tabulated in Tables 4,5,6,7. It can be seen that pine has the Lekhnitski's coefficient values within the range $\eta_{ij,i} = 0.04 - 0.06$ while beech has in the range $\eta_{ij,i} = 0.02 - 0.03$.

The $\sigma - \delta$ and $\sigma - \varepsilon$ curves are given in Figures 15- 17. Tensile strains of the woods are less than 0.60% while the tensile strains of the steels are 0.50-0.55%. The failure loads of steels are approximately 10 times greater than those of woods. Tensile tests give the Poisson's ratios as $(\nu_{31})^{oak}{}_{avg} \approx 0.232$, $(\nu_{31})^{beech}{}_{avg} \approx 0.257$ and $(\nu_{31})^{pine}{}_{avg} \approx 0.311$.

From Tables 4, 5, 6 and 7 it can be seen that, after the failure had occurred, the specimens regained 2-3 mm radial lengths. In the tests of metals such an elastic expansion can not be seen in this order. As a consequence of this, we can say that woods are flexible materials, relatively.

4.CONCLUSIONS

Experimental studies on woods show us that, woods are very complex and interesting organic materials. The Young Modulus and shear modulus values and possible yield regions were tried to be determined by the help of the tensile and torsional experiments. Stress relaxation tests and hysteresial behaviour analysis are also performed. The Lekhnitski's coefficients were tried to be determined also. All of the detected data show us that although the wood has a complex structure it is possible to determine the general behavior analysis of them by tests. The usability of the test machines for the wood type specimens produce some difficulties. Neverheless, within the approximate relative percentage error estimates the general behaviors of them and the relative differences were seen and analyzed. The experimental studies will be supported with the numerical studies in the future work in order to describe their special features numerically.

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Appendix A : Constitutive Equations for the generally orthotropic and transversely isotropic fiber composites

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{16} \\ S_{21} & S_{22} & S_{26} \\ S_{16} & S_{26} & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} \qquad [A1]$$

Equation [A1] has the elastic constants S_{11}, S_{12}, S_{16}, S_{22}, S_{26}, S_{66} and they are called as the compliance terms of the generally orthotropic plane stress problem in which they are given as;

$$S_{11} = \frac{1}{E_{11}} \qquad S_{12} = -\frac{\nu_{12}}{E_{11}} = -\frac{\nu_{22}}{E_{22}} \qquad S_{22} = \frac{1}{E_{22}} \qquad [A2]$$

$$S_{66} = \frac{1}{G_{22}} \qquad S_{16} = -\frac{\eta_{12,1}}{E_{11}} = -\frac{\eta_{1,12}}{G_{12}} \qquad S_{26} = -\frac{\eta_{12,2}}{E_{22}} = -\frac{\eta_{2,12}}{G_{12}}$$

Transversely isotropic fiber composites have five linearly independent and twelve nonzero elastic constants. Here , 1-2 plane is taken as a symmetry plane. So that, the wood specimens are accepted as the transversely isotropic type composite in which they have the same material properties through the each section of 3-axis. The strain-stress relationship is given as ;

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\ S_{12} & S_{11} & S_{13} & 0 & 0 & 0 \\ S_{13} & S_{13} & S_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(S_{11}-S_{12}) \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{bmatrix} \qquad [A3]$$

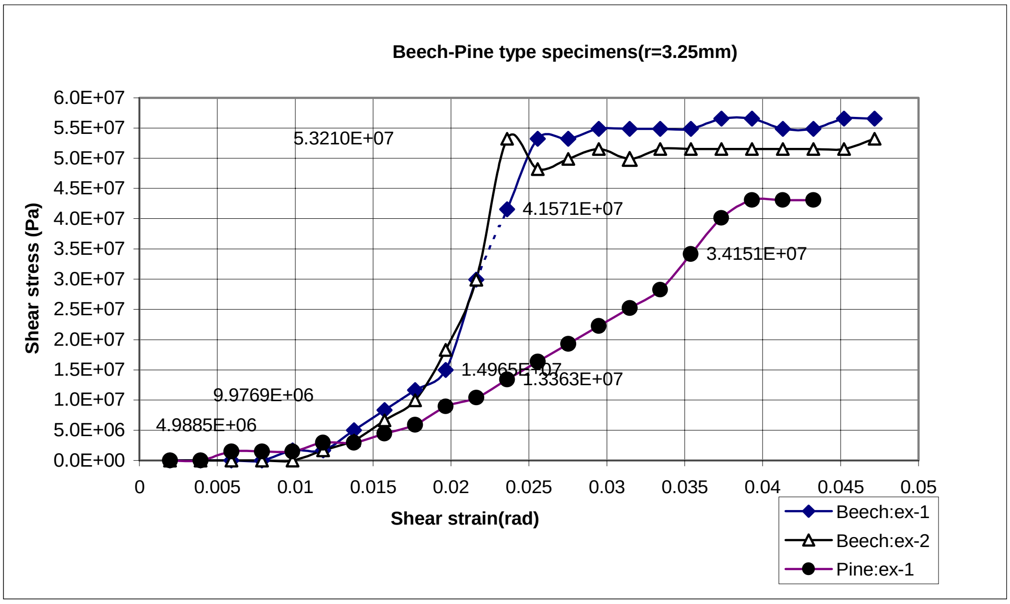

Figure 6. $\tau_{32}-\gamma_{32}$ shear stress-shear strain distribution of the Turkish beech and pine wood under torsional loading ($r = 3.25$ mm)

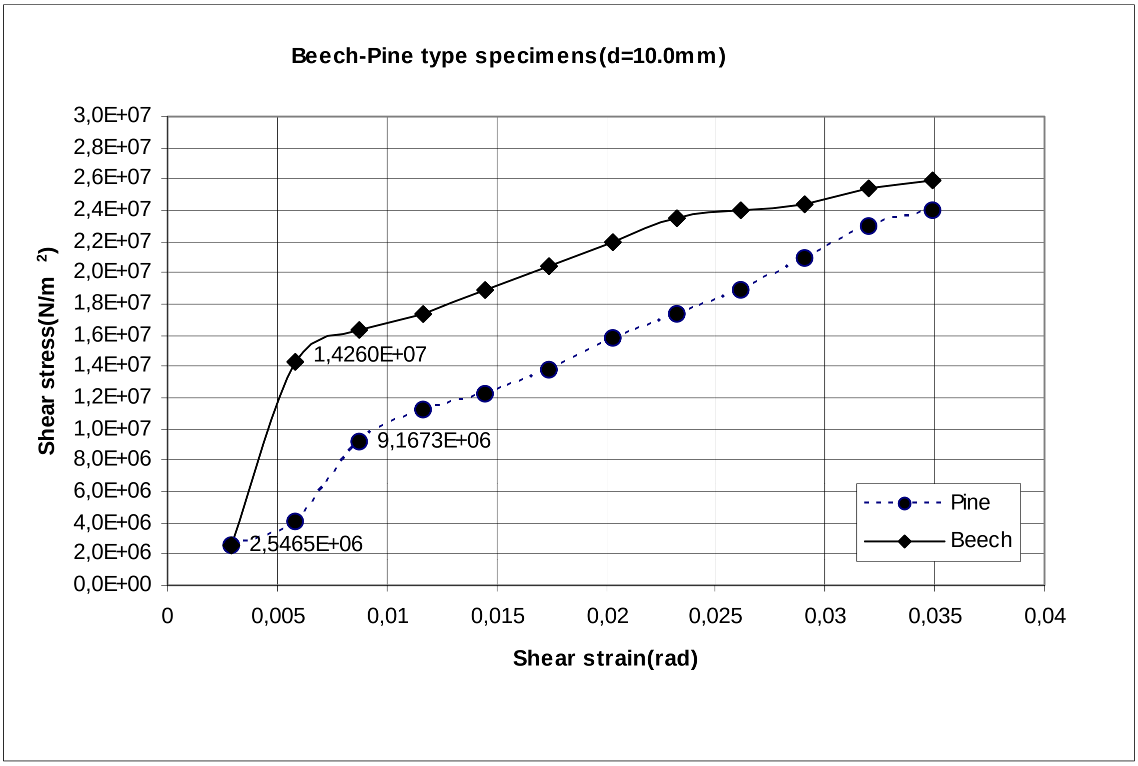

Figure 7. $\tau_{32}-\gamma_{32}$ shear stress-shear strain distribution of the Turkish beech and pine wood under torsional loading ($r = 5$ mm)

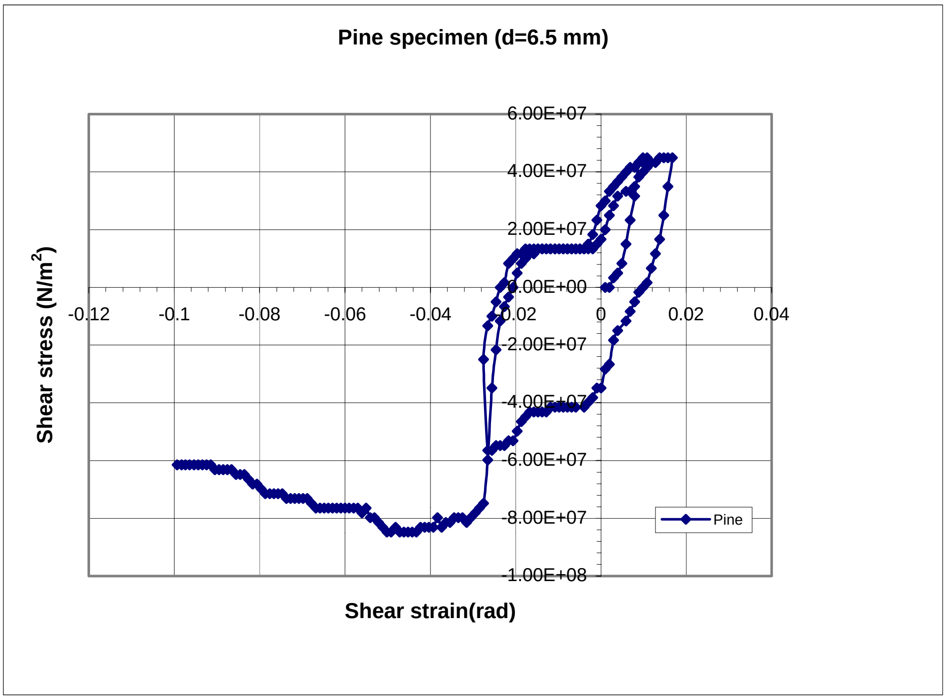

Figure 8. $\tau_{32}-\gamma_{32}$ shear stress-shear strain distribution of the Turkish pine wood under cyclic torsional loading (hysteresis loop by the specimen $r = 3.25$ mm).

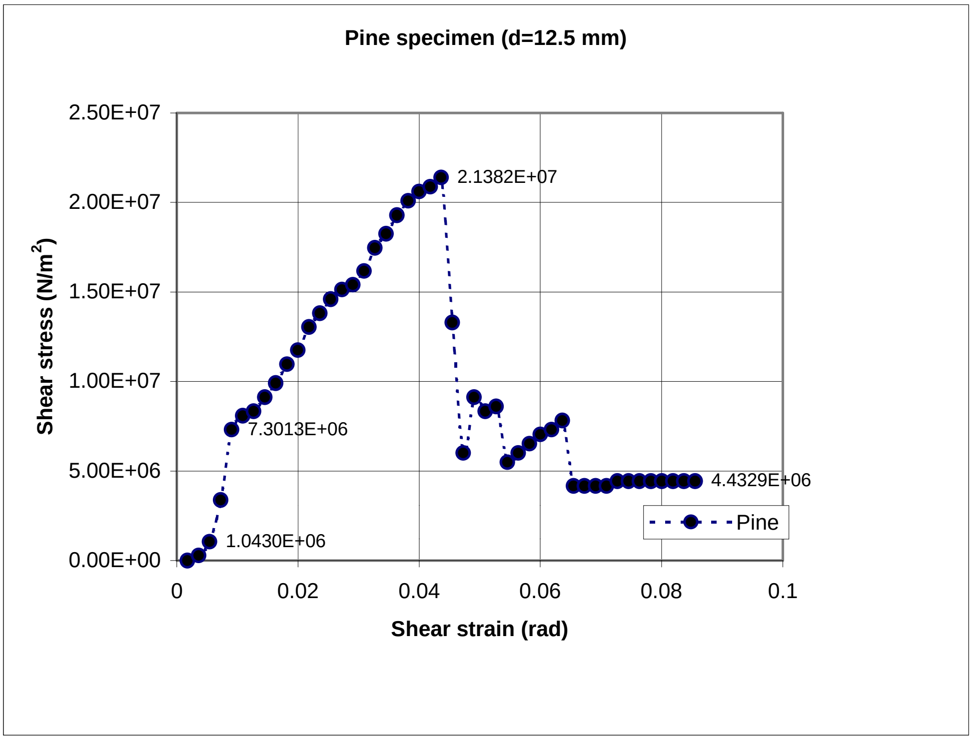

Figure 9. $\tau_{32} - \gamma_{32}$ shear stress-shear strain distribution of the Turkish pine wood under torsional loading and loading cases upto the gross failure ($r = 6.25$ mm)

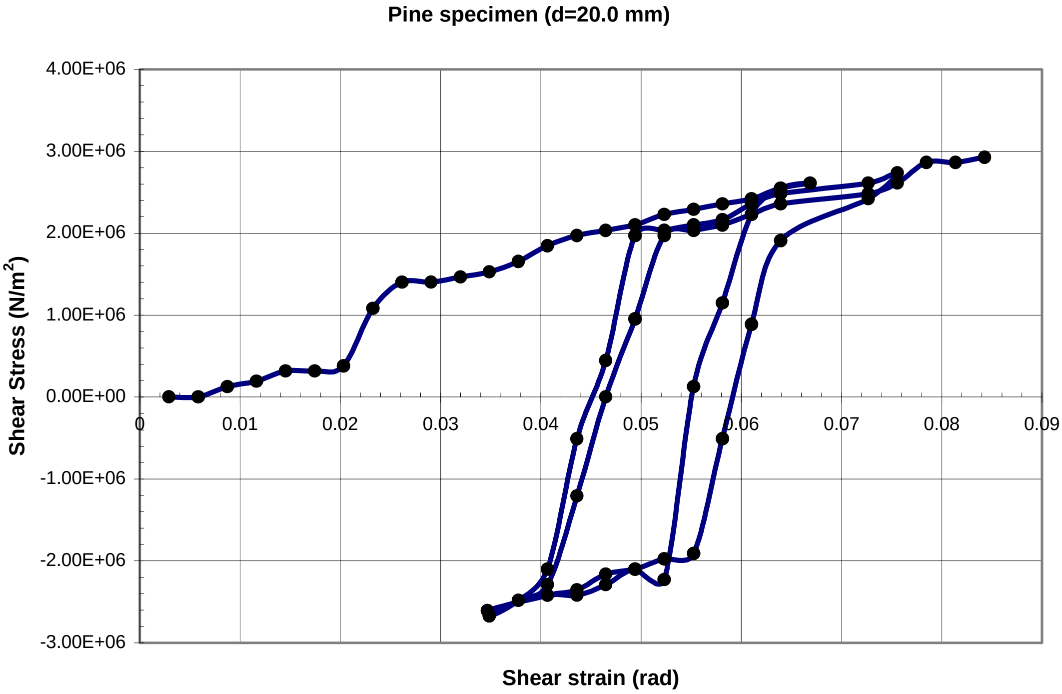

Figure 10. $\tau_{32} - \gamma_{32}$ shear stress-shear strain distribution of the Turkish pine wood under hysteresial torsional loading ($r = 10$ mm)

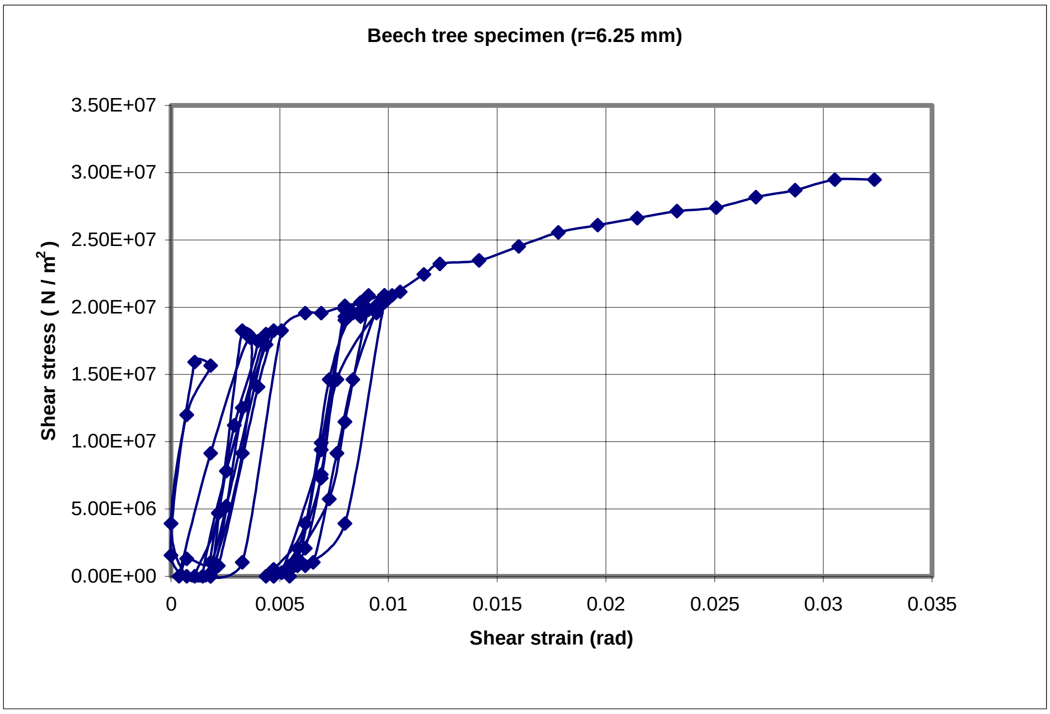

Figure 11. $\tau_{32} - \gamma_{32}$ shear stress-shear strain distribution of the Turkish beech wood under cyclic torsional loading on positive forward direction ($r = 6.25$ mm)

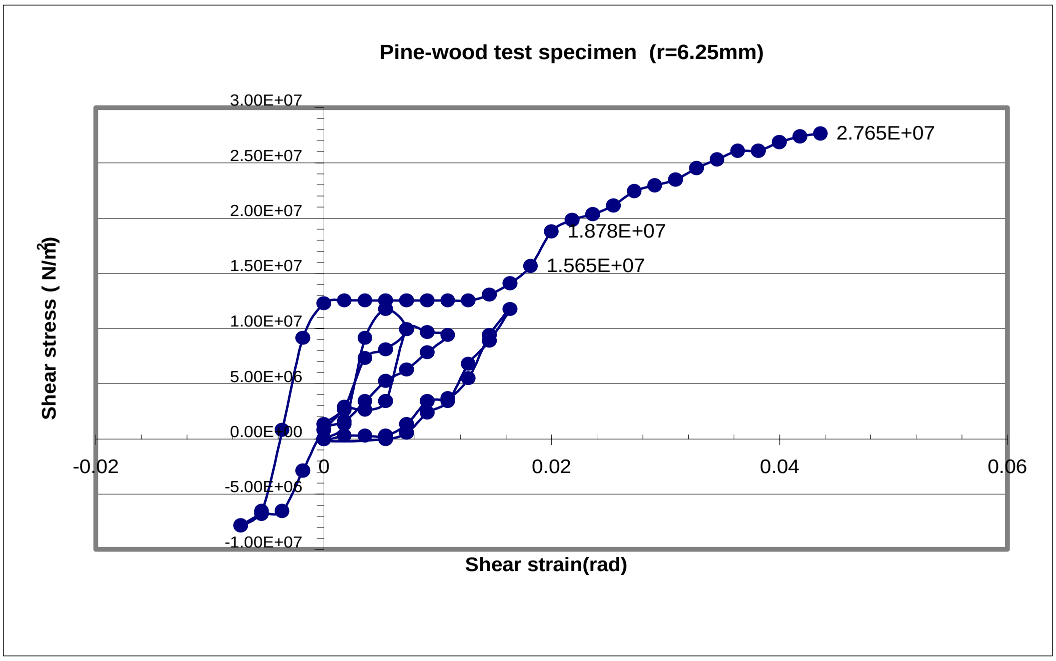

Figure 12. $\tau_{32} - \gamma_{32}$ shear stress-shear strain distribution of the Turkish pine wood under hysteresial torsional loading ($r = 6.25$ mm)

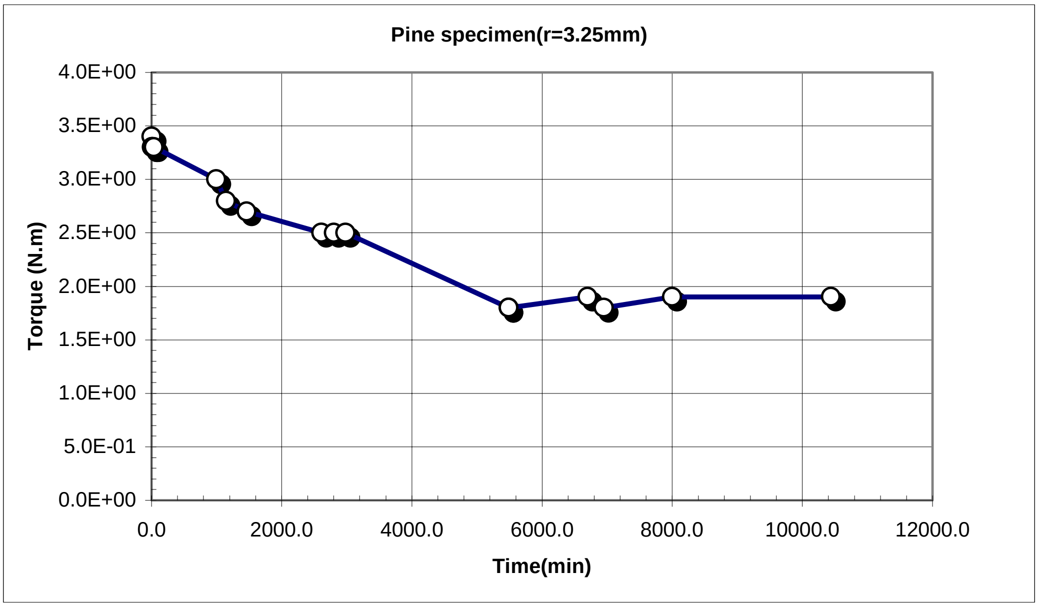

Figure 13. Stress relaxation test of theTurkish pine wood specimen under constant torsional load (r = 3.25 mm)

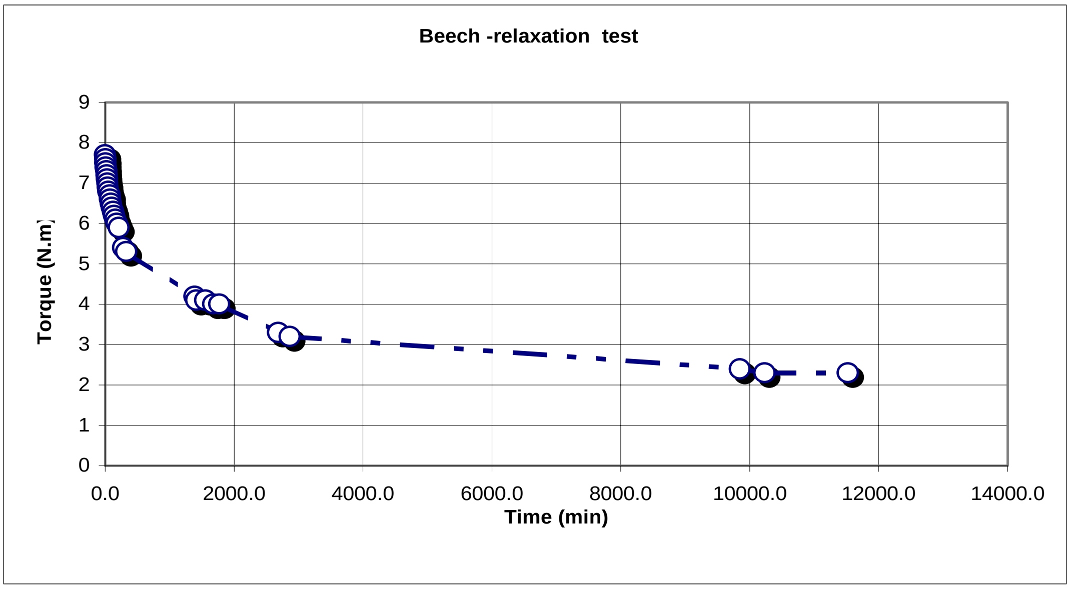

Figure 14. Stress relaxation test of theTurkish beech wood specimen under constant torsional load (r = 6.25 mm)

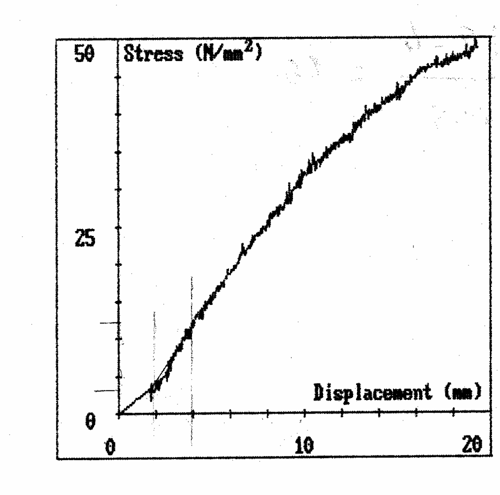

Figure 15. Tensile test of oak wood round specimen

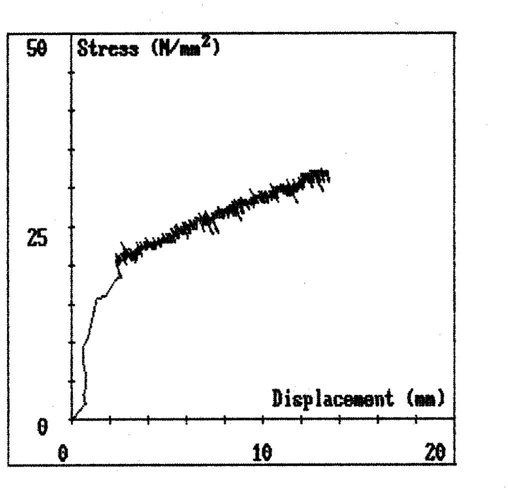

Figure 16. Tensile test of pine wood round specimen

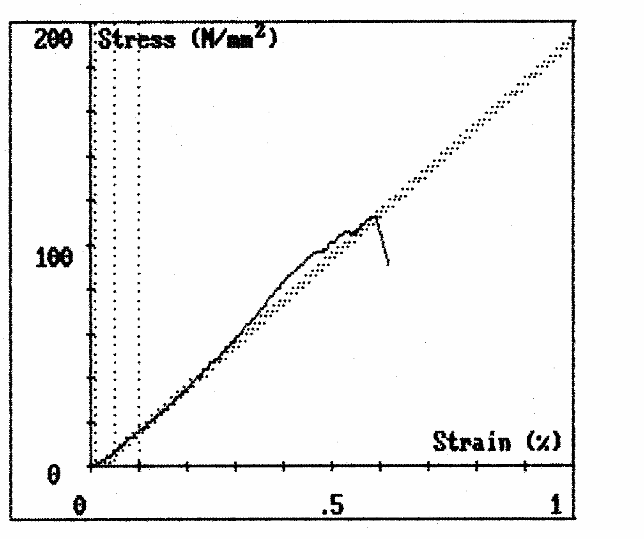

Figure 17. Tensile test of beech wood round specimen