The Prediction of Mechanical Properties of Wood-Based Composites with Vibration NDE Method

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Abstract

In this study, dynamic modulus of elasticity (MOE$_d$) of plywood, particleboard and medium density fiberboard (MDF) were determined by using a Fast Fourier Transform (FFT) analyzer and compared to their mechanical properties obtained from the same specimens. It was revealed that strong correlations between MOE$_d$ and static bending properties (MOE$_s$, MOR) were found in both longitudinal and bending vibration for particleboard. There were also good correlations between MOE$_d$ and bending properties of MDF. The MOE$_d$ in longitudinal and bending vibration is acceptable to predict the bending properties of plywood in parallel direction to long axis. However poor correlations were found between MOE$_d$ and IB in particleboard and MDF.

Keywords: NDE, vibration frequency, dynamic MOE, strength properties, wood-based composites.

1. Introduction

The physical and mechanical properties of wood-based composite products have wide variations and many factors can contribute to those such as; raw material parameters, species, resin types, manufacturing parameters including pressure, press time, temperature, machines and equipments. On the other hand, quality requirements for wood based panels have to be fulfilled as specified in standards and by customers.

Systems of quality control in the wood based panel industry are using different methods to ensure continuous production of guaranteed quality products. In order to

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evaluate the quality of wood composites, generally, full-sized panels are selected randomly from production line and small diameter specimens sawn from these panels are tested destructively. The mechanical properties of selected panels can be determined conclusively by destructive test methods. However, by the effect of numerous uncontrolled variables those values may not reflect the other panels properties, manufactured under the same conditions. The Turkish Standard, TS EN 326-2 (2006) allows alternative techniques instead of standardized tests for quality control of wood based panels if a significant correlation between measurement and standard test can be proven. Therefore, quick and accurate non-destructive evaluation (NDE) methods seem as an effective alternative to predict mechanical properties of panel products and to ensure quality requirements.

NDE have been used for many years to evaluate properties of wood products. Among the different techniques that have been used for predicting the quality of wood and wood based composite materials, one of the most commonly used methods is the stress wave NDE. It uses low stress molecular motions to measure two fundamental material properties: energy storage and dissipation. Energy storage is manifested as the speed at which a wave travels in a material. In contrast, the rate at which a wave attenuates is an indication of energy dissipation. Jayne argued that energy storage and dissipation properties are controlled by the same mechanisms that determine a material's mechanical behavior. Thus, useful mathematical relationships between stress wave and static mechanical properties should be attainable through statistical regression analysis techniques (Ross and Pellerin, 1988).

In past several years, a number of research were conducted by using NDE methods including stress wave technique in order to predict the quality of wood based composite. These studies focused on relationships between wave velocity - dynamic modulus of elasticity and static elasticity - strength properties. However, some reserchers found useful correlations among these parameters. Pellerin and Morschauser (1974) reported a good correlation between square of longitudinal wave velocity and static MOE with *r*-values of 0.93-0.95 and MOR with *r*-values of 0.87-0.93. Another research about the using of stress wave technique in wood-based composites also showed that there were strong correlations between square of longitudinal wave velocity and MOE in tensile with an *r*-value of 0.98, ultimate tensile strength with an *r*-value of 0.91, flexural MOE with an *r*-value of 0.97, and MOR with an *r*-value of 0.93. In addition, there were good correlations between dynamic MOE and static MOE in tension with an *r*-value of 0.98, ultimate tensile strength with an *r*-value of 0.93, flexural MOE with an *r*-value of 0.96, and MOR with an *r*-value of 0.92 (Ross and Pellerin, 1988).

In brief, the wave velocity and attenuation could be used successfully to predict the static tensile and flexural properties of wood based composite materials. Ross and Pellerin (1988) predicted a useful relationship between stress wave velocity and attenuation and internal bond (IB). Similarly, Vogt (1985) studied on MDF and it was found a good relationship between square of wave velocity and static MOE in tension with an *r*-value of 0.90, static MOE in bending with an *r*-value of 0.76, ultimate tensile strength with an *r*-value of 0.81, and MOR with an *r*-value of 0.96. Furthermore good correlations were achieved between dynamic MOE and static MOE in tensile with an *r*-value of 0.88, static MOE in bending with an *r*-value of 0.72, ultimate tensile strength with an *r*-value of 0.88, and MOR with an *r*-value of 0.92. It was also investigated the possibilities of using stress wave to predict internal bond strength of particleboard and structural panel products by Vogt (1986). It was reported that there were relationships between the square of wave velocity and internal bond with a correlation coefficient of 0.70-0.72 and between dynamic MOE and internal bond with a correlation coefficient of 0.80-0.99. Han et al. (2006) found that both MOE and MOR of wood based panels (plywood, oriented strandboard and particleboard) with related to moisture effect and they at different moisture contents can be estimated by observing the longitudinal wave velocity. Sotomayor (2003) found a strong relationship between static MOE and dynamic MOE based on stress wave velocity.

Some other NDE methods except stress wave technique have been also employed to estimate mechanical properties of wood-based panels. Vibration technique and ultrasound velocity, parallel and perpendicular to panel surface have been used for this purpose and good correlations were found (Bektha et al., 2000; Dunlop, 1980; Kruse, 2000; Schweitzer and Niemz, 1990; Sotomayor, 2003; Sun and Arima, 1999; Vun et al., 2000; Yang et al., 2005).

The objective of this study is to evaluate stress wave velocity and dynamic MOE of the wood based composites such as plywood, particleboard, and medium density fiberboard determined by using of longitudinal and bending vibration frequency measured by Fast Fourier Transform (FFT) analyzer and investigated the possibilities of predicting the static mechanical properties of wood based panels.

2. Material and Methods

Commercially manufactured 3 particleboards with a dimension of 18×2100×2800 mm, 3 fiberboards (MDF) with a dimension of 18×2100×2800 mm and 1 plywood with a dimension of 20×2100×2800 mm were obtained randomly from several manufacturers. The particleboards and fiberboards were manufactured from mixed species both softwood and hardwoods using urea-formaldehyde resin and the plywoods were manufactured from okoume (*Aucoumea klaineana* Pierre) veneer using phenol-formaldehyde resin. Thirty-two (16 parallel and 16 perpendicular to the sending direction) 50×500 mm specimens were cut from each particleboard and MDF panel and forty 50×500 mm specimens were cut from plywood along two grain orientation (20 parallel and 20 perpendicular direction). Totally, 40 specimens of plywood, 96 specimens of particleboard, and 96 specimens of MDF were conditioned in a room with a relative humidity of 65% ±5 and a temperature of 20 ±2°C.

In order to determine MOE_d, vibration frequencies in longitudinal and bending vibration were used. A Fast Fourier Transform (FFT) analyzer calculated the frequency of the longitudinal or bending resonance induced by hitting the end of the specimen (for longitudinal vibration) or the center of the specimen (for bending vibration), which was supported by a porous and an elastic material. The experimental setup is shown in Figure 1.

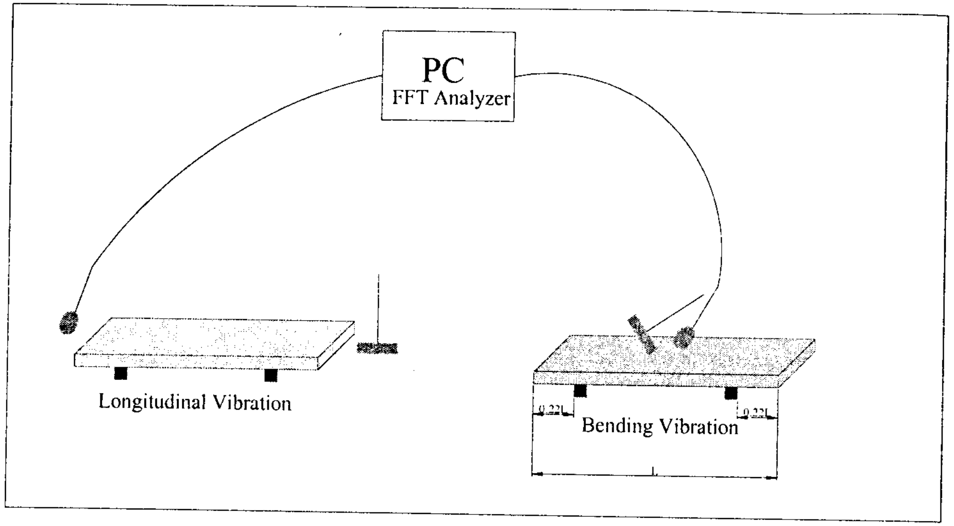

Figure 1. The experimental setup of NDE.
Şekil 1. Tahribatsız değerlendirme deney düzeneği.

The wave velocity in longitudinal vibration was determined by using of the following equation (Hearmon, 1966):

$$V = 2fl \tag{1}$$

where V is the velocity of the longitudinal stress wave, l is the length of the specimen and f is the frequency of the first longitudinal resonance mode. The dynamic modulus of elasticity in longitudinal vibration (MOE_{dl}) was calculated by using the longitudinal velocity (V) and mass density of the specimen (ρ) by the following equation (Hearmon, 1966):

$$MOE_{dl} = \rho V^2 \tag{2}$$

The dynamic modulus of elasticity in free bending vibration (MOE_{db}) was also determined by using of the Euler beam theory described by Timoshenko (1954):

$$MOE_{db} = \left(\frac{f}{\gamma}\right)^2 \frac{mL^3}{I} \tag{3}$$

where f is the frequency of bending vibration in mode no. 1, m is the mass of specimen, L is the length of specimen, I is the moment of inertia and γ is the 3.561 for free support condition mode no. 1 (Timoshenko, 1954). No shear correction was made because the effect of shear was negligible if the span to thickness ratio of the specimen was above 15 (Divos et al., 1994).

After completing the determination of the NDE parameters, the specimens for the static tests were prepared from each NDE specimens. Static modulus of elasticity

(MOE_s) and modulus of rupture (MOR) were conducted according to EN 310 (1993) in particleboard, MDF and plywood. The internal bond strength was also conducted according to EN 319 (1993) in particleboard and MDF. Totally, 40 specimens of plywood, 96 specimens of particleboard, and 96 specimens of MDF were tested for MOE_s, MOR and IB.

A simple linear regression analysis ($y = ax + b$) was performed to establish relationships between MOE_d and static stiffness and strength properties (MOE_s, MOR and IB) at a confidence level of 0.95. The correlation coefficient (r) and the standard error of regression (S_{yx}) were also calculated to evaluate the benefits of the NDE technique. As stated in the standards, the static test results of particleboard and MDF obtained from two directions that differs based on the manufacturing direction were evaluated together and the static test results of plywood were evaluated separately in two directions.

3. Results and Discussion

The results of linear regression analysis were summarized in Table 1 for particleboard, in Table 2 for MDF and in Table 3 for plywood. As shown in Tables 1-3, the strongest correlations between MOE_d that is determined nondestructively by using of both longitudinal and bending vibration frequency and bending properties (MOE_s and MOR) were obtained from particleboards.

The correlation coefficients calculated for particleboard indicated that there were strong correlations between MOE_d and MOE_s (Figure 2) and MOR (Figure 3) while it was found that a poor relationship between MOE_d and IB (Figure 4) in both longitudinal and bending vibration existed. The MOE_d-MOE_s correlation was stronger than MOE_d-MOR correlation in either longitudinal or bending vibration. In addition, the dynamic MOE determined by using of bending vibration presented slightly a better correlation than the longitudinal vibration. Consequently, the dynamic MOE determined by both longitudinal and bending frequency can be used successfully to predict the bending properties (static MOE and MOR) of particleboards. However, they are poor predictors of IB.

Table 1. The results of linear regression analysis for particleboard.
Tablo 1. Yongalevhalar için doğrusal regresyon analizi sonuçları.

	a	b	R[1]	S_{yx}[2]
Dynamic modulus of elasticity based on longitudinal vibration Boyuna vibrasyonda dinamik elastikiyet modülü				
Flexural modulus of elasticity Eğilmede elastikiyet modülü	1.12 (1.022, 1.218)[3]	-455.9 (-740.6, -171.2)	0.92	76,68
Modulus of rupture Eğilme direnci	0.07 (0.065, 0.088)	-53.71 (-86.75, -20.68)	0.81	8.89
Internal Bond Yapışma direnci	1.05×10^{-4} (-6.21×10^{-6}, 2.16×10^{-4})	0.1762 (-0.14, 0.49)	0.19	0.08
Dynamic modulus of elasticity based on bending vibration Eğilme vibrasyonda dinamik elastikiyet modülü				
Flexural modulus of elasticity Eğilmede elastikiyet modülü	0.81 (0.74, 0.88)	-288.6 (-565.6, -11.61)	0.92	78.33
Modulus of rupture Eğilme direnci	0.06 (0.05, 0.06)	-51.42 (-80.38, -22.46)	0.84	8.19
Internal Bond Yapışma direnci	7.21×10^{-5} (-9.15×10^{-6}, 1.53×10^{-4})	0.2075 (-0.10, 0.51)	0.18	0.08

[1] Correlation coefficient.
[2] Standard error of the regression.
[3] The values in parentheses are confidence bounds (p=0.05)

Table 2. The results of linear regression analysis for MDF.
Tablo 2. MDF için doğrusal regresyon analizi sonuçları.

	a	b	R[1]	S_{yx}[2]
Dynamic modulus of elasticity based on longitudinal vibration Boyuna vibrasyonda dinamik elastikiyet modülü				
Flexural modulus of elasticity Eğilmede elastikiyet modülü	1.29 (1.11, 1.47)[3]	-818.15 (-1387, -249.4)	0.83	101.38
Modulus of rupture Eğilme direnci	0.17 (0.15, 0.19)	-207.21 (-282.2, -132.5)	0.83	13.34
Internal Bond Yapışma direnci	0.1×10^{-3} (-1.5×10^{-4}, 3.9×10^{-4})	0.26 (-0.59, 1.10)	0.09	0.15
Dynamic modulus of elasticity based on bending vibration Eğilme vibrasyonda dinamik elastikiyet modülü				
Flexural modulus of elasticity Eğilmede elastikiyet modülü	0.76 (6.68×10^{-2}, 8.60×10^{-2})	190.77 (-197.1, 578.7)	0.85	94.42
Modulus of rupture Eğilme direnci	0.10 (8.75×10^{-2}, 1.13×10^{-1})	-66.03 (-119.1, -12.99)	0.84	12.91
Internal Bond Yapışma direnci	1.6×10^{-5} (-1.3×10^{-4}, 1.7×10^{-4})	0.5761 (-4.83×10^{-2}, 1.2)	0.02	0.15

[1] Correlation coefficient.
[2] Standard error of the regression.
[3] The values in parentheses are confidence bounds (p=0.05)

Table 3. The results of linear regression analysis for plywood.
Tablo 3. Kontrplaklar için doğrusal regresyon analizi sonuçları.

	a		b		R[1]		S_{yx}[2]	
	Par.[3]	Perp.[4]	Par.	Perp.	Par.	Perp.	Par.	Perp.
Dynamic modulus of elasticity based on longitudinal vibration Boyuna vibrasyonda dinamik elastikiyet modülü								
Flexural modulus of elasticity Eğilmede elastikiyet modülü	0.74 (0.416, 1.062)[5]	0.54 (0.25, 0.83)	-87.12 (-1664, 1490)	209.92 (-1221, 1641)	0.75	0.68	76.01	257.73
Modulus of rupture Eğilme direnci	0.014 (8.6×10^{-3}, 2.04×10^{-2})	5.1×10^{-3} (2.1×10^{-3}, 8.0×10^{-3})	-40.99 (-69.86, -12.13)	16.66 (2.07, 31.24)	0.77	0.64	1.39	2.63
Dynamic modulus of elasticity based on bending vibration Eğilme vibrasyonda dinamik elastikiyet modülü								
Flexural modulus of elasticity Eğilmede elastikiyet modülü	0.65 (0.50, 0.81)	0.56 (0.28, 0.83)	768.74 (122.1, 1415)	164.63 (-1157, 1487)	0.90	0.71	49.25	246.09
Modulus of rupture Eğilme direnci	0.009 (4.5×10^{-3}, 1.44×10^{-2})	0.008 (3.8×10^{-3}, 0.012)	-10.05 (-30.95, 10.85)	3.415 (-16, 22.83)	0.68	0.69	1.59	3.61

[1] Correlation coefficient.
[2] Standard error of regression.
[3] The grain direction of surface veneer is parallel to long axis.
[4] The grain direction of surface veneer is perpendicular to long axis.
[5] The values in parentheses are confidence bounds p=0.05).

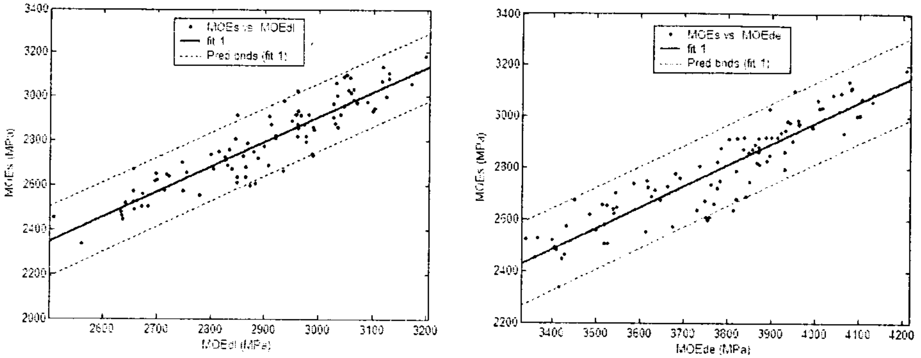

Figure 2. The relationship between MOE$_d$ and MOE$_s$ in particleboard.
Şekil 2. Yongalevhalarda MOE$_d$ ve MOE$_s$ arasındaki ilişki.

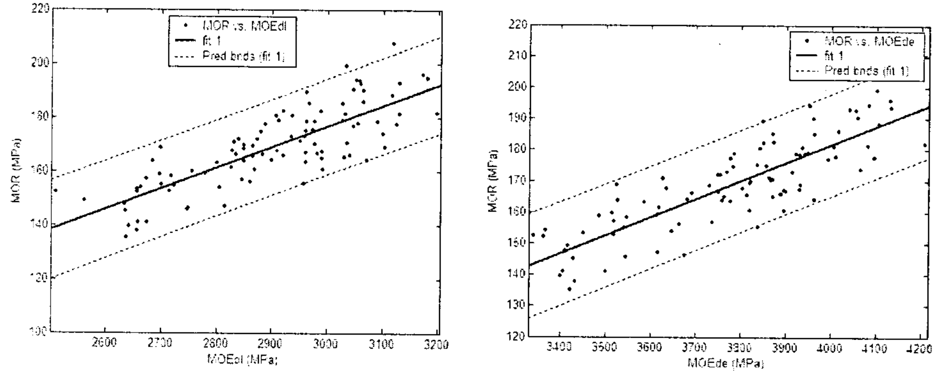

Figure 3. The relationship between MOE$_d$ and MOR in particleboard.
Şekil 3. Yongalevhalarda MOE$_d$ ve MOR arasındaki ilişki.

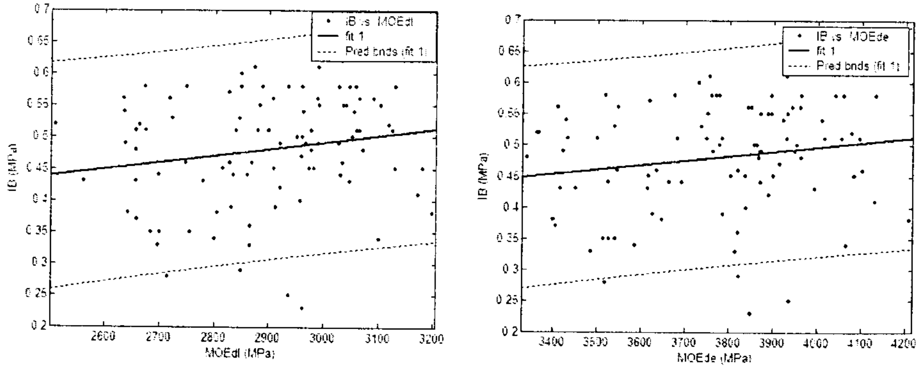

Figure 4. The relationship between MOE$_d$ and IB in particleboard.
Şekil 4. Yongalevhalarda MOE$_d$ ve IB arasındaki ilişki.

Figures 5, 6, 7 show plots of regression between MOE$_d$ and MOE$_s$, between MOE$_d$ and MOR, and between MOE$_d$ and IB of medium density fiberboards, respectively. The dynamic MOE of MDF in both longitudinal and bending vibration also showed good correlations with static MOE and MOR (Table 2). These correlations were weaker than particleboard, but stronger than plywood. However, a poor relationship was found between MOE$_d$ in longitudinal and bending vibration and IB like particleboards (Table 2). According to regression analyses, the correlations between MOE$_{de}$ and MOE$_s$ and MOR were slightly higher than MOE$_{dl}$-MOE$_s$ and MOE$_{dl}$-MOR relationships. Thus, it seems that the dynamic MOE is reliable to predict the bending properties, but it is not suitable to predict IB of MDF as experienced in particleboard.

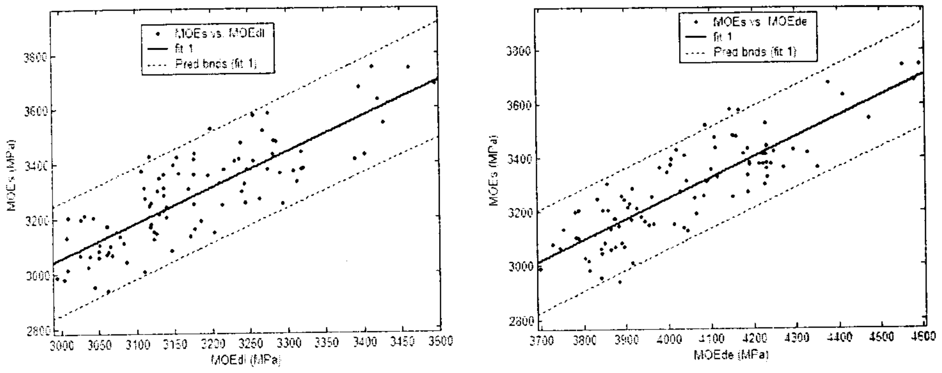

Figure 5. The relationship between MOE$_d$ and MOE$_s$ in MDF.
Şekil 5. MDF'lerde MOE$_d$ ve MOE$_s$ arasındaki ilişki.

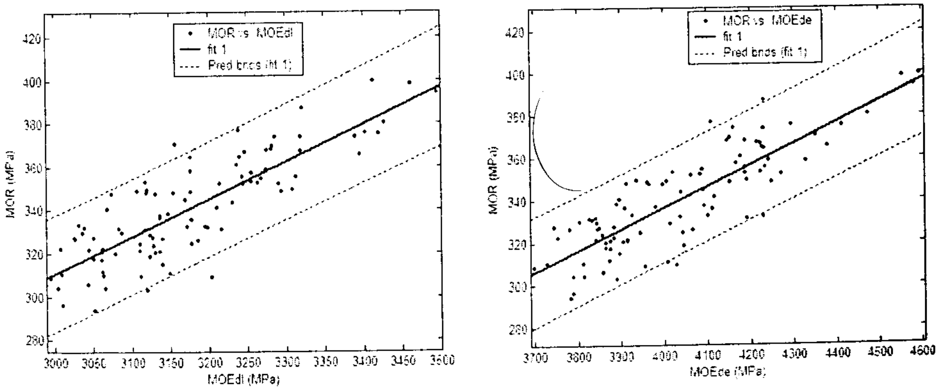

Figure 6. The relationship between MOE$_d$ and MOR in MDF.
Şekil 6. MDF'lerde MOE$_d$ ve MOR arasındaki ilişki.

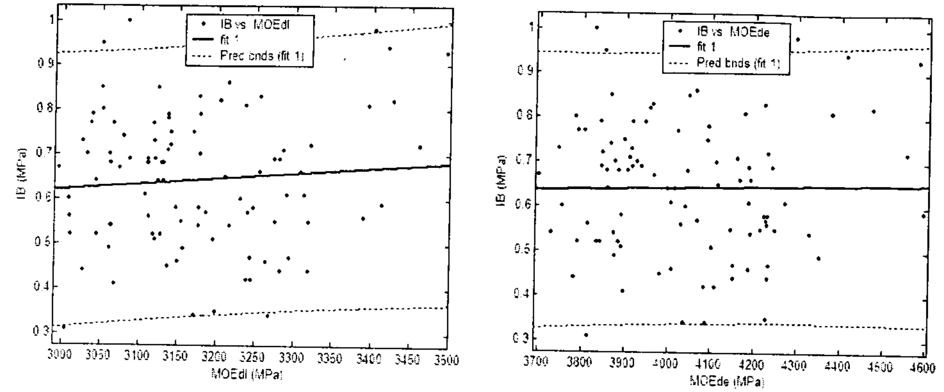

Figure 7. The relationship between MOE_d and IB in MDF.
Şekil 7. MDF'lerde MOE_d ve IB arasındaki ilişki.

Figure 8 and 9 shows plots of MOE_d-MOE_s and MOE_d-MOR relationship in parallel direction and Figure 10 and 11 shows the relationship in perpendicular direction, respectively.

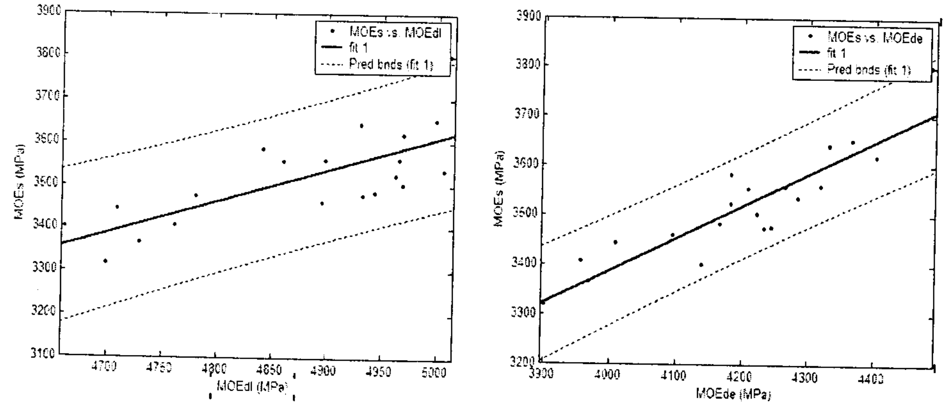

Figure 8. The MOE_d and MOE_s relationship in plywood in parallel direction.
Şekil 8. Kontrplaklarda paralel doğrultuda MOE_d ve MOE_s arasındaki ilişki.

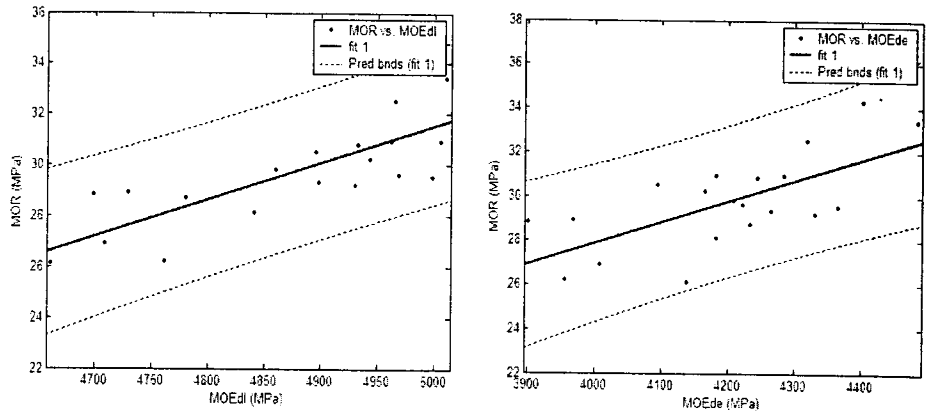

Figure 9. The MOE_d-MOR relationship in plywood in parallel direction.
Şekil 9. Kontrplaklarda paralel doğrultuda MOE_d ve MOR arasındaki ilişki.

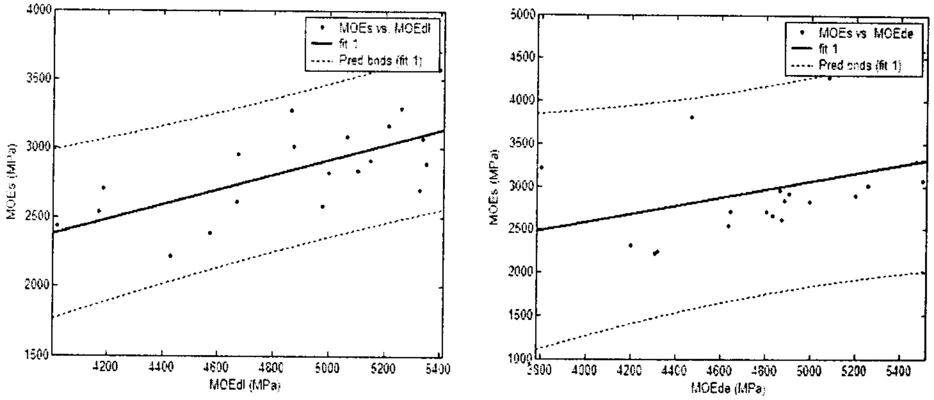

Figure 10. The MOE_d-MOE_s relationship in plywood in perpendicular direction.
Şekil 10. Kontrplaklarda dik doğrultuda MOE_d ve MOE_s arasındaki ilişki.

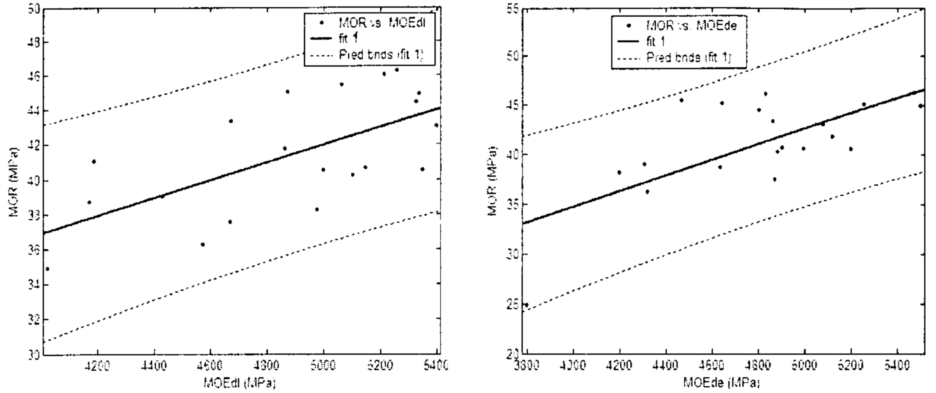

Figure 11. The MOE_d-MOR relationship in plywood in perpendicular direction.
Şekil 11. Kontrplaklarda dik doğrultuda MOE_d ve MOR arasındaki ilişki.

As shown in Table 3 and Fig. 8-11, especially MOE_{de}-MOE_s relationship was remarkable in parallel direction of plywood when compared to the others. The correlation coefficient between dynamic MOE in bending vibration and static MOE was 0.90 in parallel direction while the others varied between 0.64 and 0.77. In general, the relationships between dynamic MOE and static bending properties in parallel direction were better than perpendicular direction. Consequently, dynamic MOE in longitudinal and bending vibration is acceptable to predict the bending properties of plywood in parallel direction to long axis. However, using of dynamic MOE obtained from perpendicular direction as a predictor of static MOE and MOR may give inaccurate results when compared to the parallel direction.

4. Conclusion

Based on the findings obtained from present study, we concluded as follows:

Dynamic MOE determined nondestructively by using of both longitudinal and bending vibration frequency technique is a good predictor to estimate static bending properties (MOE and MOR) of particleboards and medium density fiberboards.

Dynamic MOE determined both longitudinal and bending vibration frequency is a poor predictor of IB of particleboard and MDF.

Dynamic MOE based on both longitudinal and bending frequency is acceptable to predict the bending properties of plywood when the grain direction of surface veneer is parallel to manufacturing direction, but it may give inaccurate results in perpendicular direction.

In general, dynamic MOE in bending vibration shows slightly better correlation with static bending properties (MOE, MOR) than longitudinal vibration.

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Odun Esaslı Levhalarda Mekanik Özelliklerin Vibrasyon Tahribatsız Değerlendirme Yöntemi ile Belirlenmesi

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Kısa Özet

Bu çalışmada kontrplak, yongalevha ve orta yoğunlukta liflevha (MDF) örneklerinde vibrasyon frekansı yöntemi ile tahribatsız olarak tespit edilen dinamik elastikiyet modülü (MOE$_d$) değerleri ile tahribatlı testlerden elde edilen mekanik özellikler arasındaki ilişkiler araştırılmıştır. Sonuç olarak yongalevhalarda hem boyuna vibrasyon hem de eğilme vibrasyonunda MOEd ile statik eğilme direnci (MOR) ve statik eğilmede elastikiyet modülü (MOE$_s$) değerleri arasında kuvvetli korelasyonlar tespit edilmiştir. Aynı şekilde MDF örneklerinde de MOE$_d$ ile MOE$_s$ ve MOR arasında iyi korelasyonlar bulunmuştur. Kontrplaklarda ise uzun eksenel paralel yönde MOE$_s$ ve MOR ile MOE$_d$ arasındaki ilişkiler Kabul edilebilir niteliktedir. Ancak uzun eksenel dik yönde elde edilen sonuçlar tatminkâr değildir. Son olarak yongalevha ve MDF'lerin yapışma direnci ile MOE$_d$ arasında bir korelasyon tespit edilememiştir.

Anahtar Kelimeler: Tahribatsız değerlendirme, vibrasyon frekansı, dinamik MOE, direnç özellikleri, odun esaslı levhalar.

1. Giriş

Odun esaslı levhaların mekanik özellikleri üretimde kullanılan hammaddelerin özelliklerinden üretim parametrelerine kadar bir dizi faktörün etkisiyle geniş bir aralıkta değişim gösterebilmektedir. Buna karşın ürünlerin sahip olması gereken asgari nitelikler ilgili standartlar tarafından belirlenmiş bulunmaktadır ve üretimin bu standartları sağlayıp sağlamadığı düzenli olarak kontrol edilmektedir. Üretim kontrolü genel olarak bir partide üretilen levhaların rasgele olarak örneklenmesi yöntemi ile yapılmaktadır. Kalite kontrol için partiden rasgele ve belli sayıda seçilen tam boyutlu levhalardan ilgili standartların öngördüğü ölçülerde küçük deney örnekleri kesilerek bunlar üzerinde klasik tahribatlı testler uygulanmakta ve elde edilen sonuçların partideki bütün levhaları temsil ettiği varsayılmaktadır. Fakat oldukça kompleks bir üretim sürecinden geçen levhalarda kontrol edilemeyen değişkenlerin etkisiyle test edilen levhalar diğer levhaları tam olarak temsil edemeyebilmektedir. Ayrıca bu şekilde test edilen levhalar artık tahrip olduğundan ekonomik bir kayıptır.

TS EN 326-2 (2006) standardı üretimde kalite kontrolü için güvenilirliği istatistik olarak ispat edilmiş alternatif yöntemlerin kullanımına izin vermektedir. Bu durumda güvenilir, pratik ve hızlı sonuç veren tahribatsız test yöntemleri üretimde kalite kontrolü için dikkate değer bir alternatif olarak karşımıza çıkmaktadır.

Geçmiş yıllarda birçok araştırmacı odun esaslı levhaların kalitesinin belirlenmesi için değişik tahribatsız test yöntemlerinin kullanılabilirliği üzerine araştırmalar yapmışlardır. Bu çalışmalarda genel olarak dalga yayılma hızı- dinamik elastikiyet modülü ve statik elastikiyet-direnç ilişkileri üzerine odaklanmışlardır. Birçok araştırmacı bu parametreler arasında kullanışlı ilişkiler bulmuşlardır (Pellerin ve Morschauser, 1974; Dunlop, 1980; Vogt, 1985, 1986; Ross ve Pelerin, 1988; Schweitzer ve Niemz, 1990; Sun ve Arima, 1999; Bektha ve diğ., 2000; Kruse, 2000; Vun ve diğ., 2000; Sotomayor, 2003; Yang ve diğ., 2005; Han ve diğ., 2006).

Bu araştırmanın amacı yongalevha, orta yoğunlukta lif levha (MDF) ve kontrplak gibi odun esaslı levha ürünlerinde Fast Foruier Transform (FFT) analizi ile stres dalgalarının oluşturduğu boyuna ve eğilme vibrasyon frekansını tespit ederek dinamik elastikiyet modülünü hesaplamak ve bunların odun esaslı levhaların statik mekanik özellikleri ile ilişkilerini ortaya koyarak, bu yolla odun esaslı levha ürünlerinin kalite özelliklerinin belirlenme olanaklarını araştırmaktır.

2. Malzeme ve Yöntem

Denemeler, ticari olarak üretilmiş 18 mm kalınlığında 3 yongalevha ve 3 MDF levha ile 20 mm kalınlığında 1 kontrplak levha üzerinde yürütülmüştür. Yongalevha ve liflevhalar iğne yapraklı ve yapraklı ağaç türlerinin karışımından üre formaldehit tutkalı kullanılarak üretilmiştir. Kontrplak ise fenol formaldehit tutkalı ile okume kaplamalarından üretilmiştir. Yongalevha ve MDF'lerin her bir panelinden 16 tanesi zımparalama yönüne paralel, 16 tanesi dik olmak üzere 32 adet ve kontrplaktan ise 20 tanesi yüzey kaplamasının lif yönü uzun eksene paralel, 20 tanesi dik olmak üzere 40 adet 50×500×levha kalınlığı mm boyutlarında örnekler hazırlanmıştır. Bu örnekler %65±5 bağıl nem ve 20±2°C sıcaklık koşullarında denge rutubetine ulaşıncaya kadar iklimlendirilmişlerdir.

Dinamik elastikiyet modülü (MOE$_d$)'nün tespiti için iki ucundan serbest olarak desteklenmiş örneğin uç kısmındaki enine kesite vurmak suretiyle oluşturulan boyuna yönde vibrasyonun ve yine aynı örnekte üst yüzeyin merkezine vurmak suretiyle oluşturulan eğilme yönünde oluşturulan vibrasyonun frekansları kullanılmıştır. Frekansı belirlemek için bir Fast Fourier Transform (FFT) analiz programından faydalanılmıştır.

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Deney düzeneği Şekil 1'de görülmektedir. Frekans yardımıyla MOEd'nin hesaplanma yöntemleri Formül 1, 2 ve 3'te verilmiştir.

Örnekler tahribatsız değerlendirmenin ardından EN 310 (1993) standardına göre eğilme direnci (MOR) ve eğilmede elastikiyet modülü (MOE$_s$) deneylerine tabi tutulmuştur. Ayrıca yongalevha ve MDF örneklerinde EN 319 (1993) standardına göre yapışma direnci (IB) denemeleri yapılmıştır.

Tahribatsız ve tahribatlı deneylerden elde edilen veriler kullanılarak basit doğrusal regresyon analizi yapılarak p= 0.05 güven düzeyinde MOE$_d$ ile MOEs, MOR ve IB arasındaki ilişkiler araştırılmıştır.

3. Sonuç ve Tartışma

Regresyon analizinden elde edilen sonuçlar yongalevha için Tablo 1, MDF için Tablo 2 ve kontrplak için Tablo 3'te verilmiştir. MOE$_d$ ile MOE$_s$ ve MOR arasındaki en güçlü korelasyonlar yongalevhalarda elde edilmiştir. Bunu MDF ve kontrplaklar takip etmiştir. Kontrplaklarda yüzey kaplaması uzun eksene paralel olan örneklerde dik olan örneklere nazaran daha kuvvetli ilişkiler bulunmuştur. Bununla birlikte, yongalevha ve MDF'lerde MOE$_d$ ile IB arasında bir ilişki kurulamamıştır. Regresyon analizi sonucunda elde edilen regresyon grafikleri Şekil 2-11'de görülmektedir.

Sonuç olarak boyuna ve eğilme vibrasyonu frekansı yardımıyla tespit edilen MOEd değeri yongalevhalarda ve MDF'lerde statik eğilme özelliklerinin (MOE$_s$ ve MOR) kestirilmesinde iyi bir veri sağlamaktadır. Ancak bu yolla yapışma direncinin kestirilmesi mümkün olmamaktadır. Kontrplaklarda yüzey kaplaması üretim yönüne paralel olarak tespit edilen MOE$_d$ değeri eğilme özelliklerinin tespit için tatminkâr sonuçlar verebilir. Ancak dik yönde yeterli güvenilirliğe sahip olmadığı düşünülmektedir. Son olarak eğilme vibrasyonundan elde edilen MOEd ile statik eğilme özellikleri arasındaki ilişkiler, boyuna vibrasyonla elde edilenlere nazaran bir miktar daha iyi bulunmuştur.

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