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Determination of physical and mechanical properties of plywood produced using beech, okoume and ozigo species

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ABSTRACT **Research Article**

Wood and wood-based materials are widely used in the construction industry in the world. The sustainable and renewable nature of wood is seen as an important advantage in contrast to non-renewable resources such as aluminum, steel, concrete, and plastic. In order to protect the advantages of wood and eliminate / reduce its disadvantages, plywood, particle board, fiber board, LVL, CLT, wood plastic composites etc. such as new wood-based engineering products are produced. Plywoods are widely used in automotive, construction, furniture, and many industries. In our country, plywoods are produced using tropical species as well as native tree species. In this study, density, water absorption, thickness swelling, bending resistance, elasticity of modulus in bending and shear strength values of plywood made of beech, okoume and ozigo wood species are investigated. Comparison of plywood produced from tropical species with beech has been made. It has been determined that beech plywood has higher density than okoume and ozigo plywood. It has been determined that beech plywood has higher density than okoume and ozigo plywood. It has been observed that there is a linear relationship between the bending strength, elasticity modulus and shear strength values of beech plywood and their full dry density.

Key Words: Plywood, beech, okoume, ozigo, shear strength

Kayın, okume ve ozigo türleri kullanılarak üretilen kontrplakların fiziksel ve mekanik özelliklerinin belirlenmesi

ÖZ

Dünyada ahşap ve ahşap kökenli malzemeler inşaat sektöründe yaygın olarak kullanılmaktadır. Ahşap malzemenin sürdürülebilir ve yenilenebilir olması alüminyum, çelik, beton ve plastik gibi yenilenemeyen kaynakların aksine önemli bir avantaj olarak görülmektedir. Ahşap malzemenin sahip olduğu avantajların korunarak dezavantajlarının giderilebilmesi / azaltılabilmesi için kontrplak, yonga levha, lif levha, LVL, CLT, odun plastik kompozitleri vb. gibi yeni ahşap kökenli mühendislik ürünleri üretilmektedir. Kontrplaklar otomotiv, inşaat, mobilya ve birçok endüstride yaygın olarak kullanılmaktadır. Ülkemizde kontrplaklar yerli ağaç türlerinin yanı sıra tropik türler kullanılarak da üretilmektedirler. Bu çalışmada kayın, okume ve ozigo türlerinden üretilmiş kontrplakların yoğunluk, su alma, kalınlığına şişme, eğilme direnci, eğilmede elastikiyet modülü ve çekme makaslama direnci değerleri araştırılmıştır. Tropik türlerden üretilen kontrplakların yerli tür olan kayın ile kıyaslaması yapılmıştır. Kayın kontrplaklar, okume ve ozigo kontrplaklardan daha yüksek yoğunluğa sahip olduğu belirlenmiştir. Kayın, okume ve ozigo kontrplakların yoğunlukları, masif haldeki yoğunluklarına göre daha yüksek olduğu anlaşılmıştır. Kayın kontrplakların eğilme direnci, elastikiyet modülü ve çekme makaslama direnci değerleri ile tam kuru yoğunlukları arasında doğrusal bir ilişki olduğu görülmüştür.

Anahtar Kelimeler: Kontrplak, kayın, okume, ozigo, çekme makaslama direnci

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1. Introduction

Wood and wood-based materials are widely used in the construction industry in the world. The sustainability and renewability of wood material is seen as an important advantage in contrast to non-renewable resources such as aluminum, steel, concrete and plastic. Compared to other building materials, wood is a very important building material in that it consumes less energy in its production and therefore causes less CO_2 emission to the nature (Gustavsson and Sathre, 2006; Van den Bulcke et al., 2009). In addition to these advantages of wood material, it also has many disadvantages such as low resistance to biological hazards, not being in a homogeneous structure, low dimensional stabilization, and having different physical and mechanical properties in three directions (Demirkir and Colakoglu, 2015; Bal et al., 2016).

Wood-based engineering products such as plywood, particleboard, fiberboard, LVL, CLT, wood-plastic composites, etc. are produced in order to protect the advantages of wood material and eliminate / reduce its disadvantages (Efe and Kasal, 2007; Demirkir et al., 2013; Temiz et al., 2016). Veneer-based products, especially plywood, which are mostly used in structural applications, are important due to their versatile use and lower cost compared to other composite materials. According to FAO data, world veneer and plywood production is 163 million m^3 in 2018, and the amount of production is expected to increase in the coming years (Buddi et al., 2017; FAO, 2018; Nicolao et al., 2022).

Plywood is widely used due to its features such as having higher dimensional stability and easy processing compared to wood and other wood-based materials (Colakoglu, 1996; Bal and Bektas, 2013). In addition to using native species in their production, some imported tropical species such as okoume and ozigo are also used. Okoume is a tropical tree species with high mechanical properties compared to its low density. Plywoods produced using okoume are generally used as marine plywood (Brunck et al., 1991; Negro et al., 2011).

Ozigo, which is a medium-density (0.50 – 0.59 gr/cm^3) wood species, is highly resistant to marine hazards despite its low biological resistance. Its machinability is more difficult than okoume. It can be peeled off with or without steaming. Although its adhesive properties are good, some problems may arise in adhesives containing phenol. Nail and screw withdrawal resistance properties are quite good. Its wood is especially used in the production of plywood. On the other hand, it is used in the automotive industry in the production of car bodies, joinery, furniture, carpentry, parquet, stairs, paneling, boat bodies, etc. (UTP, 2022).

In this study, it was aimed to determine the density, water absorption, thickness swelling, bending strength, modulus of elasticity in bending (MOE) and shear strength values of plywood produced from beech, okoume and ozigo species. Comparison of the plywood produced from tropical species with the native beech species was made.

2. Material and Method

In this study, plywoods obtained from beech (*Fagus orientalis* L.), okoume (*Aucoumea klaineana pierre*) and ozigo (*Dacryodes buettneri*) species obtained from a plywood factory operating in Kastamonu province were used (Figure 1). All of the plywood is 7 layers, first class and 12mm thick. Phenol formaldehyde adhesive (Polifen 47) obtained from Polisan company (Turkiye) was used in their production. In the production of plywood, the amount of adhesive is 160 gr/m^2, the press temperature is 114 °C, the press pressure is 110 bar/m^2 and the pressing time is 16 minutes.

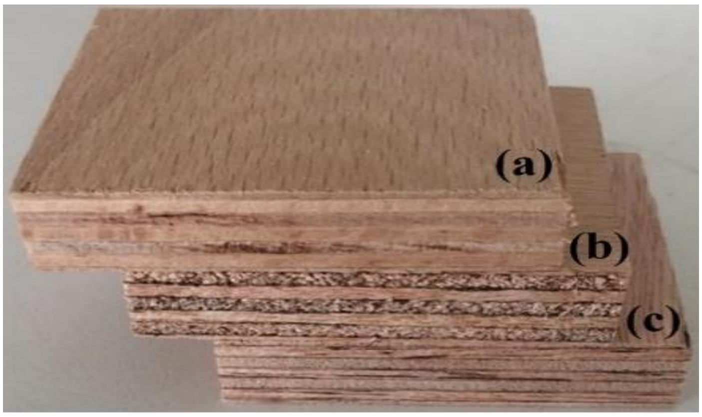

Figure 1. Plywoods produced from beech (a), okoume (b) and ozigo (c) species

The water absorption and thickness swelling tests of the plywood were determined according to the TS EN 317 (1999) standard and their densities were determined according to the TS EN 323 (1999) standard. The water absorption and thickness swelling rates of the plywood were calculated according to Equation 1 and Equation 2, respectively. All samples prepared according to the relevant standards were kept at 20±2 ℃ and 65% relative humidity until their weights did not change.

$$WA = \frac{A_1 - A_0}{A_1} x\ 100 \qquad (1)$$

Where; WA, water absorption rate (%); A_0, weight before water absorption (g); A_1, weight after water absorption (g), of the plywoods.

$$TS = \frac{T_1 - T_0}{T_1} x\ 100 \qquad (2)$$

Where; TS, thickness swelling rate (%); T_0, thickness before water absorption (mm); T_1, thickness after water absorption (mm), of the plywoods.

In order to determine bending strength and MOE, samples of 50 mm width and 290 mm length were prepared according to the TS EN 310 (1999) standard. Bending strength and MOE were calculated according to Equation 3 and Equation 4, respectively. In order to determine shear strength of plywoods, the principles specified in the TS EN 314 (1998) standard were used. The shear strength was calculated according to Equation 5. The prepared samples were tested after conditioning. Shimadzu AGIC/20/50KN universal testing machine was used to determine the mechanical tests. Experiments were performed with 10 replicates in each test group (Figure 2).

$$\sigma_{bw} = \frac{3\ x\ P_{max}\ x\ l}{2\ x\ b\ x\ h^2}\ N/mm^2 \qquad (3)$$

Where; σ_{bw}, bending strength (N/mm^2); Pmax, max load (N); l, span (mm); b, width of cross section (mm); h, depth of cross section (mm), of the plywoods.

$$E_w = \frac{P\ x\ l^3}{4\ x\ b\ x\ h^3\ x\ f}\ N/mm^2 \quad (4)$$

Where; E_w, modulus of elasticity in bending (N/mm^2); P, increment of load on the straight line portion of the load deformation curve (N); l, span (mm); b, width of cross section (mm); h, depth of cross section (mm); f, increment of deformation corresponding (mm), of the plywoods.

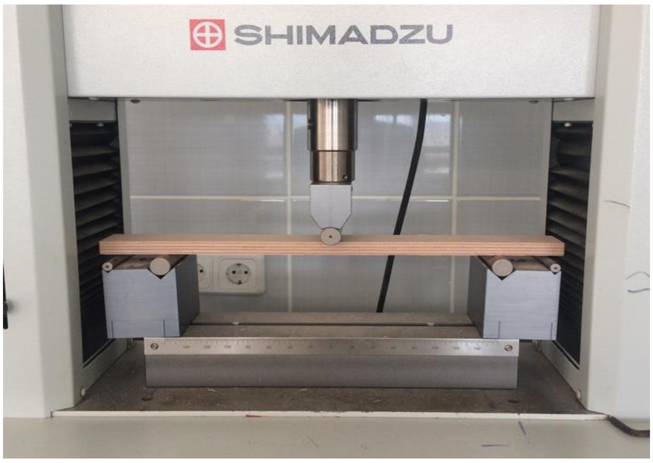

Figure 2. Conducting bending strength and MOE tests

$$\tau_B = \frac{T}{L\ x\ b}\ N/mm^2 \quad (5)$$

Where; τ_B, shear strength (N/mm^2); F, rupture force (N); L, length of shearing area (mm); b, width of shearing area (mm), of the plywoods.

IBM SPSS 23.0 application was used for statistical evaluation of the obtained data. Analysis of variance was applied to determine the differences between the results.

$$\tau_B = \frac{T}{L\ x\ b}\ N/mm^2 \quad (6)$$

Where; τ_B, shear strength (N/mm^2); F, rupture force (N); L, length of shearing area (mm); b, width of shearing area (mm), of the plywoods.

IBM SPSS 23.0 application was used for statistical evaluation of the obtained data. Analysis of variance was applied to determine the differences between the results.

3. Results and Discussion

According to the results of the tests carried out, the densities of beech, okoume and ozigo plywood can be seen in Table 1.

Table 1. Density of plywoods according to humidity

Plywood type	Oven dry density (gr/cm^3)	Air dry density (gr/cm^3)	Waterlogged density (gr/cm^3)
Beech	0.74^c (0.03)*	0.78^d (0.03)	0.97^f (0.05)
Okoume	0.46^a (0.05)	0.48^a (0.03)	0.72^c (0.04)
Ozigo	0.56^b (0.06)	0.60^b (0.05)	0.86^e (0.04)

* Values in parentheses represent the standard deviation.

Considering the oven dry, air dry and waterlogged densities in Table 1, the highest density was obtained in beech plywood. Beech plywood is followed by ozigo and okoume plywood, respectively. In the literature, it is reported that the oven dry density values of beech, okoume and ozigo species are 0.62 gr/cm^3, 0.37 gr/cm^3 and 0.53 gr/cm^3 respectively (Bal and Bektas, 2018; Reyes et al., 1992). According to the results, it was understood that the densities of the plywood obtained from beech, okoume and ozigo species were higher than the densities in the solid wood. It is thought that this increase is due to the adhesive used in plywood production and the densification of the veneers during pressing (Jakob et al., 2020; Kurowska et al., 2010; Salca et al., 2020).

The water absorption and thickness swelling graphs of the plywoods can be seen in Figure 3. When the water absorption graph is examined, it is seen that okoume plywoods (82.35%) absorb the most water. This is followed by ozigo (62.84%) and beech (43.36%) plywoods, respectively. When the graph of thickness swelling is examined, the highest thickness swelling occurred in beech plywoods (4.13%). This is followed by ozigo (3.65%) and okoume (2.83%) plywoods, respectively.

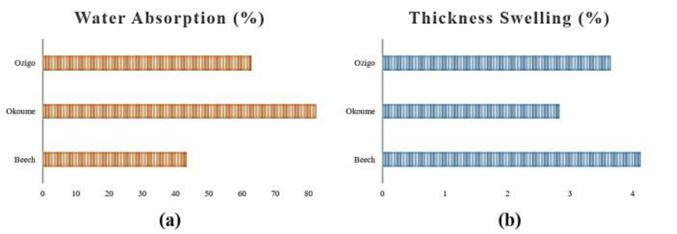

Figure 3. Plywoods' water absorption (a) and thickness swelling (b) graphs (%)

Bending strength, MOE and shear strength values of beech, ozigo and okoume plywood can be seen in Table 2.

Table 2. Variance analysis results of plywood bending strength, modulus of elasticity in bending and shear strength ($p<0.001$)

Plywood type	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Shear strength (N/mm^2)
Beech	75.03^a (0.83)*	9893.42^a (35.42)	2.66^a (0.14)
Okoume	49.55^c (0.75)	5344.06^c (53.72)	1.29^c (0.10)
Ozigo	62.57^b (0.68)	6884.64^b (46.11)	1.56^b (0.37)

* Values in parentheses represent the standard deviation.

All analyzed features in Table 2 showed statistically significant changes ($p<0.001$). The highest bending strength was obtained in beech plywood with 75.03 N/mm^2, and the lowest bending strength was obtained in okoume plywood with 49.55 N/mm^2. When the MOE values are examined, it is understood that the trend in bending resistance has not changed. The highest MOE was 9893.42 N/mm^2 in beech plywood, and the lowest MOE was 5344.06 N/mm^2 in okoume plywood. In the literature, it is seen that the trend between the bending strength and MOE values of beech, okoume and ozigo woods and the results obtained from plywoods are similar (Ors et al., 2002; Efe and Imirzi, 2007; Tan and Colakoglu, 2010).

When the shear strength results are examined, it is understood that the best adhesion occurs in beech plywood. Beech plywood is followed by ozigo and okoume plywood. It can be said that one of the main reasons why beech plywood has a better shear strength than ozigo and okoume plywood is the density difference (Chow and Chunsi, 1979; Namara and Waters, 1970; Örs et al., 2002).

4. Conclusions

In this study, the physical and mechanical properties of plywood obtained from beech, okoume and ozigo species were determined. According to the results obtained;

- Beech plywoods were determined to have higher density than okoume and ozigo plywoods.

- It has been understood that the densities of beech, okoume and ozigo plywoods are higher than their densities in solid wood.

- It has been observed that there is a linear relationship between the bending strength, MOE and shear strength values of beech plywoods and their oven dry densities.

- It is recommended to investigate the technological properties of plywood obtained from different native tree species and plywood obtained from tropical species in future studies.

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