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**Karbon Fiber (CFRP) ile Güçlendirilmiş Lamine Ağaç Malzemenin Bazı Mekanik Özelliklerinin Belirlenmesi**

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**Özet:** Bu çalışmada, karbon fiberle güçlendirilmiş lamine edilen ahşap yapıların bazı mekanik özelliklerinin etkisinin belirlenmesi amaçlanmıştır. Doğu kayını (*Fagus orientalis* L.) odunundan hazırlanan örneklere çift bileşenli epoksi yapıştırıcısı ve nem kürlenmeli poliüretan tutkalı kullanılarak lamine levhalar elde edilmiştir. Lamine levhaların mukavvemetini arttırmak için karbon fiber (CFRP) yapı malzemesi uygulanmıştır. Örneklere TS 2474 standardına göre statik eğilme, TS 2478 standardına göre eğilmede elastikiyet modülü ve TS 2477 standardına göre dinamik eğilme (şok) testleri uygulanmıştır. Deney sonuçlarına göre, en yüksek statik eğilme direnci değeri 132.80 N/mm2 ile ahşap katmanlar arasında karbon fiber yapı malzemesi kullanılan ve epoksi yapıştırıcı ile yapıştırılan lamine levhalarda elde edilmiştir. En yüksek eğilmede elastikiyet modülü değeri 14004.83 N/mm2 ile ahşap katmanlar etrafı karbon fiber yapı malzemesi ile kaplanmış ve ahşap katmanlar arası epoksi yapıştırıcısı ile yapıştırılan lamine levhalarda elde edilmiştir. En yüksek dinamik eğilme (şok) direnci değeri 0.62 kgm /cm2 ile ahşap katmanlar etrafı karbon fiber yapı malzemesi ile kaplanmış ve ahşap katmanlar arası epoksi yapıştırıcısı ile yapıştırılan lamine levhalarda bulunmuştur. Sonuç olarak, karbon fiber yapı malzemesi ve epoksi yapıştırıcı, köprü, merdiven, kolon, kiriş ve çatı gibi yapılarda bölgesel takviye amacıyla eğilmeye ve baskıya maruz kalan bölümlerinde kullanılabilir. Ağaç malzemenin zarar görmesi, ahşap malzemenin dış yüzeyine verilebilecek ani etkilere karşı karbon fiber yapı malzemesi ve epoksi yapıştırıcı kullanılarak önlenebilir. Uygulanan yüzeye epoksi yapıştırıcının güçlü ve hızlı nüfuz etmesi ve karbon fiber yapı malzemesi ile artan mukavemeti sayesinde, özellikle ahşaptan yapılan zeminlerde yıpranma süresini uzatmak için kullanılabilir.

**Anahtar Kelimeler:** Lamine Ağaç Malzeme, Karbon Fiber (CFRP), Yapıştırıcılar, Mekanik Özellikler.

**Determination of Some Mechanical Properties of Laminated Wood Material Reinforced with Carbon Fiber (CFRP)**

**Abstract:** In this study, it was aimed to determine the effect of some mechanical properties of structural laminated wood reinforced with carbon fiber. Laminated sheets were obtained using moisture curing polyurethane and two component epoxy adhesives prepared from Oriental beech (Fagus orientalis L.) wood samples. Carbon fiber (CFRP) structural material was applied to laminated sheets in order to increase their strength. Static bending test was made according to TS 2474, bending in elasticity modulus was made according to 2478, and dynamic bending (shock) test was made according to 2477 standards. According to results of the experiments, the highest static bending strength value (132.80 N/mm2) was obtained in laminated sheets used carbon fiber building material between wooden layers and bonded with epoxy adhesive. The highest elasticity modulus in bending value (14004.83 N/mm2) was determined in laminated sheets bonded with epoxy adhesive between wooden layers and covered with carbon fiber structural material around sheets. The highest dynamic bending (shock) strength value (0.62 kgm/cm2) was found in laminated sheets bonded with epoxy adhesive between wooden layers and covered with carbon fiber structural material around sheets. Consequently, carbon fiber building material and epoxy adhesive can be used in sections which are exposed to bending and stress such as bridge, stair, column, beam, and roof for local reinforcement. Damage of wood material can be prevented by using carbon fiber construction material and epoxy adhesive against the sudden effects that might be caused to the outside of the wood material. Due to the strong and fast penetration of the epoxy adhesive on the applied surface and the increased strength with the carbon fiber building material, it can be used to extend the wear time especially on the floors made of wood.

**Keywords:** Laminated Wood Material, Carbon Fiber (CFRP), Adhesives, Mechanical properties.

1. **Introduction**

Wood laminating materials are obtained by bonding two or more layers with adhesive and joining the fiber directions of the layers parallel or perpendicular to each other. Preparing the fiber directions in parallel is widely used. Different type of wood, variable number of floor, different size, shapes, and coat thicknesses can be applied in lamination (Kurtoglu, 1979). If lamination technique is applied as an alternative to wood material, also if the lapel coatings used in laminates are impregnated, the service life will increase (Ozcifci, 2001). The wooden lamination technique ensures that the wood material is more resistant to external factors. Nowadays, carbon fiber reinforced lamination processes are used in a wide range of fields from the construction sector to the furniture sector.

Carbon fibers are mostly used in the construction industry for column cladding and curtain methods. In addition to these, they are used in more various methods around the world. These materials, commonly known as carbon fiber (carbon fiber), are a new generation materials of lightweight, high strength, thin, fast and practicable, corrosion resistant, long lasting durability adjustable by changing the sequencing orientation of the fibers (Güler and Subasi, 2012). When carbon fiber material is used in wood materials, it seems to have a property of increasing strength. Borri and Corradi (2005) studied on behaviors under loads of wood structural systems reinforced with carbon fiber reinforced polymers. They obtained positive results from carbon fiber-reinforced materials.

Roberto et al. (2004) investigated on the structural classification of reinforced parts with fiber-reinforced composite plates of fully damaged wooden columns. The bending tests performed revealed that there was a 60% improvement in fiber reinforced composite sheets in the resultant data. Chen (1999) studied the mechanical performances of fiber-reinforced wood assemblies reinforced with glass-fiber reinforced wood joints in numerical analysis of numerical analysis and experimental works under the microscope. In the experimental studies made, the strengthening surfaces were observed under the microscope and it was observed that there was a serious improvement in the stress intensity in the joint regions.

In this work, it is aimed at how the carbon fiber (CFRP) reinforcement application used for reinforcing wooden structural elements influences some mechanical properties of laminated elements.

1. **Material and Method**

**2.1. Wood Material**

As a test material, Oriental beech (*Fagus orientalis* L.) was used. It is a material that full-dry density (D0) 0. 68 g/cm3, air-dry density (Dl2) 0.72 g/cm3. Also, its elasticity module is 15700 MPa, bending strength (σE) is 120 MPa, tensile strength in parallel with the fibers (σg) is 132 MPa, the compression strength parallel to the fibers (σB) is 60 MPa (Bozkurt and Erdin, 2000).

**2.2. Adhesives**

Epoxy adhesive was provided by Dost Kimya Industrial Raw Materials Industry and Trade. Ltd. Co. It is a double component adhesive which is used for adhering solid materials to glossy surfaces, resistant to chemicals, providing excellent adhesion to concrete, wood, steel and plastic materials and reaching the desired mechanical strength very quickly. It was used with carbon fiber for the bonding of epoxy concrete elements, iron, steel and similar metals, types of wood and glass and assembly operations exposed to heavy and medium loads. Its density is 1.5 g / cm3 at 20 oC and its viscosity is 1100 mPas. Usage of 200 g/m2 in compliance with the company's proposal ([www.kompozit.net](http://www.kompozit.net), 2017).

Moisture curing polyurethane adhesive was provided by SBC Kimya Industrial Raw Materials Industry and Trade. Ltd. Co. It is adhesive that has resistant to water and moisture, solvent-free, one-component polyurethane based. Also, it is preferred in sea and lake vehicles, metal and wood parts of the installation and repair. Its density is 1.11 ± 0.02 g / cm3 at 20 oC and 14,000 ± 3,000 mPas at 25 oC. It hardens in 30 minutes at 20 oC ± 2 temperature and 65 ± 3 relative humidity environment. According to the manufacturer's recommendations, this adhesive is recommended to be applied to the package viscosity and to the surfaces at a rate of 150 g /m2 until the absorption is high, as well as slightly moisturizing the dried surfaces (Altinok, 1988).

**2.3. Carbon Fiber (CFRP) Construction Material**

In this study, the carbon fiber building materials have a density of 300 g/m2 with 1.2 mm thickness in the dimension and form suitable for the strengthening work to be carried out. This material was provided by Dost Kimya Industrial Raw Materials Industry and Trade. Ltd. Co. It is a high abrasion resistance and extremely rigid material that high resistance compared to steel, very low density compared to metal. In addition, chemical resistance is high, light and unlimited size is suitable for production. Carbon fiber reinforced composite materials are generally used for used in aircraft industry, in rocket and satellite construction, in automotive industry, and in the construction of many sporting goods (Yildizhan, 2008).

**2.4. Preparation of Experimental Examples**

Experimental samples are provided according to TS 2470 standards by 'Random selection' method from timber enterprises in Karabük industry. Then, laminated sheets were obtained adding moisture curing polyurethane and two component epoxy adhesives and carbon fiber construction material. Component a (resin) and component b (hardener) of the two component epoxy adhesive used in the study were mixed 1/1 rate until a light gray color and applied with a spatula to the applied surface at 200 g/m2. At the same time, care has been taken to cut the carbon fiber material properly with a modeling knife for the purposes of the fibers do not break off. The cut carbon fiber construction material was bonded with epoxy adhesive between and around of laminated sheets. The samples were subjected to press 2.5 kg/cm2 press pressure, 200 0C degree temperature and under 60 minute wait period. Then, the specimens were brought to the intended dimensions in appropriate standards for each test group. The types and numbers of laminated sheets belong to test types was given in Table 1.

Table 1. Number of laminated samples belonging to experimental species.

|  |  |  |
| --- | --- | --- |
| **Experiment Type** | **Sample type** | **Number** |
| Static bending strength and elasticity modulus in bending | Epoxy between wood layers and carbon fiber around wood layers | 10 |
| Polyurethane between wooden layers and carbon fiber around wood layers | 10 |
| Carbon fiber and epoxy between wood layers (CFRP+epoxy) | 10 |
| Epoxy between wood layers | 10 |
| Polyurethane between wood layers | 10 |
| Dynamic bending (shock) strength | Epoxy between wood layers and carbon fiber around wood layers | 10 |
| Polyurethane between wooden layers and carbon fiber around wood layers | 10 |
| Carbon fiber and epoxy between wood layers (CFRP+epoxy) | 10 |
| Epoxy between wood layers | 10 |
| Polyurethane between wood layers | 10 |

**2.5. Test Method**

**2.5.1. Air-Dry Density**

The moisture content of the test samples was determined according to TS 2471, densities was determined according to TS 2472 standards. The test specimens were weighed on a 0.01 g precision scale after waited until being allowed to reach constant weight at 20 ± 2 °C and 65% relative humidity in cabinet. After, the dimensions were measured by caliper in ± 0.01 mm sensitivity. Air-dry density (δ12) value was determined in the following formula that according to air-dry weight (M12) and air-dry volume (V12) values.

(1)

**2.5.2. Static Bending Strength and Elasticity Modulus in Bending Strength Test**

Bending test was made according to TS 2474, elasticity modulus in bending was made according to TS 2478. The following equations have been used in the calculation of the bending strength and elasticity modulus in bending:

(2)

Here in;

Fm=Bending strength (N/mm2)

Fmax = Maximum force at break (N)

L = Distance between supporting axes (mm)

b= Width of the test sample (mm)

h= Height of the test sample (mm)

(3)

Here in;

Em= Elasticity modulus in bending(N/mm2)

L1= Distance between supporting axes (mm)

b= Sample width(mm)

h= Sample height (mm)

F2-F1= Load increase of load-deflection diagram ratios region (N)

a2-a1 = Due to the increase in strength, deflection difference in the middle of the sample length (mm)

**2.5.3. Dynamic Bending (Shock) Strength Test**

For the dynamic bending (shock) strength test, each test sample was obtained in four layers with dimensions of 5x20x320 mm. The test specimens were cut to dimensions of 20x20x360 mm according to TS 2477 standard. The dynamic bending strength was calculated with a pendulum hammer. Impact hammer with has 10 kg/m of work power, which is freely dropped from a certain height, is used to break some of the has kinetic energy in the first position to break the sample.

(4)

Here,

w : Spend energy to break (kg.m)

b : Example width (cm)

h: Example height (cm), it expresses this information.

**2.6. Statistical Evaluation of Data**

Mechanical test results were evaluated by a computerized statistical program composed of analysis of variance and following DUNCAN test at the 95% confidence level. Statistical evaluations were made on homogeneity groups (HG), of which different letters reflected statistical significance.

**3. Results and Discussion**

**3.1. Results of Air-Dry Density**

The mean values of air-dry density for the laminated samples are given in Table 2.

Table 2. Mean values for air-dry density.

|  |  |  |
| --- | --- | --- |
| **No** | **Sample type** | **Average (g/cm3)** |
| 1 | Epoxy between layers and CFRP around layers | 1.79 |
| 2 | Polyurethane between layers and CFRP around layers | 1.68 |
| 3 | CFRP and epoxy between layers (CFRP+epoxy) | 1.77 |
| 4 | Epoxy between layers (control) | 1.72 |
| 5 | Polyurethane between layers (control) | 0.78 |

As a result of the experiments, the highest air-dry density value (1.79 g/cm3) was obtained in laminated sheets bonded with epoxy between wood layers and covered with carbon fiber around wood layers. The lowest air-dry density value (0.78 g/cm3) was found in laminated sheets bonded with polyurethane between wood layers (control).

**3.2. Results of Static Bending Strength Test**

The arithmetic average values of static bending strengthtest are given in Table 3.

Table 3. Arithmetic mean values of static bending strength test (N/mm2).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Sample type** | **Bending strength ( N/mm2)** | **Standard deviation** | **Homogeneity group** |
| 1 | Epoxy between layers and CFRP around layers | 129.10 | 13.51 | AB |
| 2 | Polyurethane between layers and CFRP around layers | 124.96 | 20.06 | B |
| 3 | CFRP and epoxy between layers (CFRP+epoxy) | 132.80 | 29.73 | A |
| 4 | Epoxy between layers (control) | 101.10 | 3.46 | C |
| 5 | Polyurethane between layers (control) | 93.80 | 4.95 | CD |

According to Table 3, the highest static bending strength value (132.80 N/mm2) was obtained in laminated sheets used carbon between wooden layers and bonded with epoxy adhesive. Mistak (2013) was examined that bending strengths by obtaining laminated sheets with Scotch pine wood material and different fiber fabrics. As a result, the highest strength (81.54 N/mm2) was obtained in polyurethane-based resin and carbon fiber fabric (CFRP) reinforced Scotch pine samples. In a similar study by Premrov et al. (2004) obtained a 50% higher strength in bending strength of carbon fiber reinforced wood structural members. In literature, Radford et al. (2002) obtained 25% more strength after laminated wooden bridge beams were strengthen with glass-reinforced composites against bending and stretching. Accordingly, it is supported with the information in the literature that the carbon fiber material placed in the intermediate layers of the laminated elements increase the bending strength of samples. The reason for this is that the has high wear resistance of the carbon fiber construction material and has the high tear resistance of the epoxy adhesive can be said affect the bending strength positively in laminated samples.

Also statistically, polyurethane (control) and epoxy (control) samples were found in the same homogeneity group. However, no statistically significant difference in laminated sheets were found in covered with carbon fiber and Epoxy adhesive between wood layers, epoxy adhesive between layers and covered with carbon fiber around layers, polyurethane between layers and covered with carbon fiber around layers. The results of the variance analysis to determine which factor the difference is due to in different groups are given in Table 4.

Table 4. Results of variance analysis of static bending strength test.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variance source** | **Sum of squares** | [**Degrees of freedom**](http://tureng.com/tr/turkce-ingilizce/degrees%20of%20freedom) | **Average of squares** | **F (Account)** | **P value (p≤0.05)** |
| Interaction | 647908.13 | 1 | 647908.13 | 2151.01 | 0.00 |
| Adhesive | 327.070 | 1 | 327.07 | 1.086 | 0.03 |
| Coating | 10839.19 | 2 | 5419.59 | 17.99 | 0.00 |
| Adhesive\* Coating | 24.996 | 1 | 24.99 | 0.08 | 0.02 |
| Error | 13554.45 | 45 | 301.21 |  |  |
| Total | 702981.43 | 50 |  |  |  |

According to the results, the effect of wood species, type of adhesive and adhesive-coating interactions on bending strength (p≤0.05) was found to be significant.

**3.3. Results of Elasticity Modulus in Bending Strength Test**

The arithmetic mean values for the modulus of elasticity in bending strength of laminated samples are given in Table 5.

Table 5. The arithmetic mean values of elasticity modulus in bending strength (N/mm2).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Sample type** | **Modulus of elasticity (N/mm2)** | **Standard deviation** | **Homogeneity group** |
| 1 | Epoxy between layers and CFRP around layers | 14004.83 | 1418.97 | A |
| 2 | Polyurethane between layers and CFRP around layers | 13457.65 | 2828.57 | A |
| 3 | CFRP and epoxy between layers (CFRP+epoxy) | 13351.93 | 1758.35 | A |
| 4 | Epoxy between layers (control) | 9929.99 | 470.32 | B |
| 5 | Polyurethane between layers (control) | 9272.85 | 1112.31 | B |

According to Table 5, the highest elasticity modulus in bending value (14004.83 N/mm2) was obtained in laminated sheets bonded with epoxy adhesives between wooden layers and covered with carbon fiber around sheets. A statistically difference was found between the results of the experiments and the laminated samples. The results of variance analysis to determine the effect of different species on the modulus of elasticity are given in Table 6.

Table 6. Results of variance analysis of elasticity modulus in static bending strength.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variance source** | **Sum of squares** | **Degrees of freedom** | **Average of squares** | **F**  **(Account)** | **P value**  **(p≤0.05)** |
| Interaction | 6.86 | 1 | 6.86 | 2356.95 | 0.00 |
| Adhesive | 3625972.67 | 1 | 3625972.67 | 1.24 | 0.00 |
| Coating | 1.83 | 2 | 9.16 | 31.46 | 0,00 |
| Adhesive\* Coating | 30225.25 | 1 | 30225.25 | 0.01 | 0.00 |
| Error | 1.31 | 45 | 2912910.15 |  |  |
| Total | 7.53 | 50 |  |  |  |

It was determined that the effect of adhesive-type and adhesive-coating interaction on the modulus of elasticity in bending was statistically significant.

**3.4. Results of Dynamic Bending (Shock) Strength Test**

The arithmetic mean results related to dynamic bending (shock) strength values of the test specimens are given in Table 7.

Tab. 7. Arithmetic mean results of the dynamic bending (shock) strength test (kgm/cm2).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Sample type** | **Shock**  **Strength (kgm/cm2)** | **Standard deviation** | **Homogeneity group** |
| 1 | Epoxy between layers and CFRP around layers | 0.62 | 0.24 | A |
| 2 | Polyurethane between layers and CFRP around layers | 0.53 | 0.20 | B |
| 3 | CFRP and epoxy between layers (CFRP+epoxy) | 0.56 | 0.21 | AB |
| 4 | Epoxy between layers (control) | 0.50 | 0.21 | B |
| 5 | Polyurethane between layers (control) | 0.36 | 0.20 | C |

The highest dynamic bending (shock) strength value (0.62 kgm/cm2) was found in laminated sheets bonded with epoxy adhesives between wooden layers and covered with carbon fiber around sheets. It was obtained that reinforcement applications of bonded with epoxy between wood layers and covered with carbon fiber around wood layers have an effect on increasing the value of dynamic bending strength in general. Polyurethane and epoxy adhesive samples used as adhesives were found in different homogeneity groups. However, a statistically significant difference in samples was found between polyurethane between layers, epoxy between layers and covered with carbon fiber around layers.

According to this, the results of analysis of variance made to determine the effect of laminated groups on dynamic bending strength are given in Table 8.

Table 8. Results of variance analysis of the dynamic bending (shock) strength experiment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variance source** | **Sum of squares** | [**Degrees of freedom**](http://tureng.com/tr/turkce-ingilizce/degrees%20of%20freedom) | **Average of squares** | **F**  **(Account)** | **P value**  **(p≤0.05)** |
| Interaction | 0.09 | 1 | 0.09 | 618.30 | 0.00 |
| Adhesive | 0.02 | 1 | 0.02 | 3.66 | 0.03 |
| Coating | 0.09 | 2 | 0.004 | 27.55 | 0.00 |
| Adhesive\* Coating | 0.04 | 1 | 0.01 | 3.66 | 0.02 |
| Error | 0.02 | 45 | 0.01 |  |  |
| Total | 0.12 | 50 |  |  |  |

The effect on dynamic bending strength of coating type (p≤0.05) was found to be significant. Also, the effect of type of adhesive and adhesive-coating interaction on dynamic bending (shock) strength was found to be significant at 95% confidence interval.

1. **Conclusions**

According to results of the experiments, the highest static bending strength value (132.80 N/mm2) was obtained in laminated sheets used carbon fiber building material between wooden layers and bonded with epoxy adhesive Also, an increase of 41.57% was observed compared to the control groups.The highest elasticity modulus in bending value (14004.83 N/mm2) was determined in laminated sheets bonded with epoxy adhesives between wooden layers and covered with carbon fiber around sheets also an increase of 51.03% was observed compared to the control group.

The highest dynamic bending (shock) strength value (0.62 kgm/cm2) was found in laminated sheets bonded with epoxy adhesives between wooden layers and covered with carbon fiber around sheets also an increase of 72.22% was observed compared to the control group.

As a result, it can be used to reinforce structural elements such as wooden columns, beams, etc. on wooden floors, which are continuously and suddenly exposed to pressure by using carbon fiber material and epoxy adhesive between and around laminates. Carbon fiber can be preferred for timber structural sections subjected to stretching due to its high flexing and breaking properties. Also, due to the strong and fast penetration of the epoxy on the applied surface and the increased strength with carbon fiber, it can be used to extend the wear time especially on the floors made of wood.

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