DETERMINATION OF SOME PERFORMANCE CHARACTERISTICS OF CONSTRUCTION TIMERS FROM LAMINATED WOOD MODIFIED WITH CARBON FIBER

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Summary

The purpose of this study is to determine some of the performance properties of building lumber from laminated veneer lumber, modified with carbon fiber. In the study, 3 European spruce (Picea abies) trees of various thicknesses and unidirectional carbon fiber material were used as wood raw materials. The carbon fiber fabrics used are suitable for 4 different applications. Epoxy and polyurethane adhesives are used as glue. It complies with TS 5497 EN 408 standard for flexural strength and modulus of elasticity tests, TS EN 317 standards for water absorption and dimensional swelling rate, and EN 302-1 / 2004 standards for adhesion resistance tests. According to the test results, the maximum static bending resistance of the specimens was 73,324 N / mm2 in laminated specimens using a single layer of CFRP building material and epoxy adhesive, while the average flexural modulus was a maximum of 11831.797 N / mm2 in specimens. obtained by coating epoxy resin with carbon fiber. As a result of dimensional stability tests, the greatest increase in weight change (57.03%) for laminated specimens glued with epoxy resin, the maximum increase in thickness change (68.05%) for laminated specimens held together with two-layer polyurethane adhesive on the inner surface, maximum increase in width change The effect of adhesive and CFRP adhesive interaction on adhesion resistance was significant at a 95% confidence interval in tensile shear tests.

Tests have shown that CFRP reinforcement can be easily used in multilayer beams. Substantial improvements have been made in some mechanical properties and dimensional changes due to water. Using carbon fiber epoxy adhesive helps to protect the wood surface from external factors.

Key words: laminated wood material, carbon fiber (carbon fiber), adhesives, mechanical properties.

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1. Introduction

Wood sandwich elements are obtained by gluing two or more layers and joining the layers so that the fiber directions are parallel or perpendicular to each other. The arrangement of fibers parallel to it is more often used. If the wood laminate produced is bent, the grain directions of the layers must be parallel. Different types of wood, different number of layers, different sizes, shapes and thicknesses can be used for lamination (Kurtoglu, 1979). In order for the lamination technique to have more durable properties, it is necessary to use the wood material in the best possible way, eliminating its defects. By applying the lamination technique, it is possible to produce products of higher quality and the desired shape through design. The use of these products is higher than that of solid wood materials, and they have many advantages. With this method, a longer and wider wood material can be produced from wood of short and narrow widths. This reduces the cost of this product as there is little waste when using short-blasted wood products. Since the layer thickness and color of the wood material are different for laminated materials made from solid parts, the aesthetic value is higher. (Karayilmazlar et al., 2007) Carbon fiber-reinforced lamination processes originate in the construction sector and are today found throughout all stages of production. When research on strengthening is being researched; It can be seen that most of the research on fiber-reinforced polymer composites reinforced with glass fibers, carbon fibers and aramid fibers of building materials. The main reason for using these materials is that they are more resistant to corrosion and many external factors. In the CFRP reinforcement method, carbon fiber is applied to the outer surface of all reinforced concrete building elements, and the reinforced walls are covered with plaster and plasterboard on the outside to give the walls a look. The bricks and walls in the structure, reinforced with CFRP, reduce the vibrations of the structure back and forth during an earthquake, thereby reducing the risk of building damage from an earthquake. (V. Klukhikh et al., 2010). In his study, Altay (2014) aimed to determine the effect of carbon fiber reinforcement application used in strengthening wooden building elements on the physical and mechanical properties of laminated elements. The samples prepared from beech (Fagus orientalis L.) wood were laminated using two-component epoxy and moisture curing polyurethane adhesives. Carbon fiber (CFRP) was applied in order to increase the strength of laminated elements.Alshegri (2019) investigated the suitability of using non-corroding CFRP (carbon fiber reinforced plastic) instead of steel plates in terms of mechanical strength in his study "Investigation of the Use of Carbon Fiber Reinforced Polymer Sheets in the Joints of Wooden Structures". . As a result of the cantilever bending test, it was determined that the strength of the samples reinforced with carbon fiber increased 60% in L joints, 67% in T joints and 80% in 45 ° miter joints, depending on the strength of the samples reinforced with steel plates.

In this study, it was studied to improve the mechanical and physical properties of laminated timbers using carbon fiber building material, and accordingly, to build and develop structures that would last longer during fire and earthquakes. By improving the properties of laminated timbers, durable and economical wood construction elements have been produced.

2. Material method

2.1. Wood material

In selecting the raw materials to be used in the study, preference was given to raw materials widely used in industry and available in the literature. One tree species, European spruce (Picea abies), was selected as the raw material for the study. The choice of this type as a preference is due to the use of spruce and pine in wooden structures today. It is a material with a total dry density (D0) of 0.47 g / cm3 and an air-dry density (Dl2) of 0.43 g / cm3. In addition, the modulus of elasticity is 10,000 N / mm2, bending strength (σE) 68 N / mm2, tensile strength parallel to the fibers (σg) 80 N / mm2, shear strength (σB) 7.5 N / mm2 (Bozkurt and Erdin , 2000)

2.2 Adhesives

Epoxy and polyurethane adhesive, ACM Yapı Kimyasalları San. Teak. LLC Şti. This was provided by the company. Typically, two-component epoxy resins, like other thermosetting plastics, change from liquid to solid over a period of time and reach final hardness upon maturation within a week. The combination of fiberglass or carbon fiber with epoxy resin has excellent mechanical strength. ... Epoxy resin is also a surface coating product. It is also used as a paint or primer. Its density is 1.5 g / cm3 at 20oC and its viscosity is 1100 MPa. The method of use corresponds to the recommendations of the company - 300 g / m2.

The main properties of polyurethane adhesives are durability, good adhesion to any surface, no shrinkage, thixotropy, excellent adhesion strength with full adhesion to equipment, heat resistance. Its density is 1.11 ± 0.02 g / cm3 at 20 ° C, it cures in 30 minutes at 20 ° C ± 2 and 65 ± 3% relative humidity. According to the manufacturer's recommendations, this glue has a packing viscosity and hardener of 87%, and when preparing this glue, 13% was used in accordance with the company's recommendations of 300 g / m2.

2.3 Carbon fiber

SPM Composites and Advanced Materials Technology Co., Ltd. Şti. The CFRP building material obtained from the company was investigated and the flat pattern CFRP building material with a thickness of 1.2mm and a density of 600g / m2 was preferred as a size and shape suitable for reinforcement work. It has a low density compared to metals, high strength compared to steel, is extremely strong and has high wear resistance. In addition, it can be manufactured with high chemical resistance, lightness and unlimited length. Composite materials reinforced with carbon fiber in general; It is used in aircraft construction, rocket and satellite production, automobile construction, and many types of sports equipment (Altay, 2014).

2.4 Preparation of test pieces

Akkoyun Orman Ürünleri San was used as wood material in the study. Ltd. Provided by the company. It is noted that the wood material used is also first class, without cracks or knots. The wood samples were cut on a circular saw to the size of the laminated veneer lumber to be produced. Moisture curable polyurethane, two-component epoxy adhesives, and carbon fiber structural material were added to the cut samples and then laminated. Part a (resin) and part b (hardener) of the two-part epoxy adhesive used in the study were mixed at a 1/1 ratio to light gray and applied to the surface with a brush at 300 ° C g / m2. The wood that will be used in preparing the test pieces will have knots, cracks, etc., which will affect the bending characteristics. Visually checked for absence. The solid wood that has been conditioned and reaches standard moisture values ​​prepares for a smooth surface suitable for gluing. Glued wooden beams were formed from 5 layers (lamellas), the thickness of the lamellas was 8 mm, 16 mm, 24 mm. At the same time, in the preparation of the CFRP building material, care was taken to ensure that the fibers were cut properly so that no tearing occurred. The cut CFRP building material is glued between the lamellas and on the top side with epoxy and polyurethane glue. After gluing the samples, they were tortured. However, the resulting samples were brought to the desired size in the appropriate standards for each experimental group.

2.5 Experimental methods

2.5.1. Density of air drying

The test pieces were conditioned at a temperature of 20 ° C ± 2 and a relative humidity of 65 ± 5% and adjusted to a humidity of 12%. Samples for determining the density were prepared with the dimensions of the cross-section of glued wood and a length of 100 mm. When determining the density, the principles of TS 5497 EN 408 were followed. The prepared samples were conditioned at a temperature of 20 ºC ± 2 and a relative humidity of 65 ± 5% and brought to a humidity of 12%. Sample sizes will be measured to the nearest 0.01 mm and sample volumes will be determined by multiplying these values ​​by each other. Then the weight of each sample was determined using an analytical balance capable of weighing with an accuracy of 0.01 g. The density of air drying was determined using the formula below.



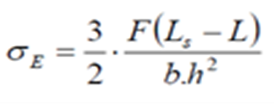
d = density (g / cm3)

m = sample weight (g)

v = Sample volume (cm3)

2.5.2. Static flexural strength and flexural modulus

TS 5497 EN 408 standard was met in flexural strength and flexural modulus tests. The force is applied from two symmetrical points about the center of the structural material of the appropriate size. The equations below are used to calculate flexural strength and flexural modulus.



σE = Flexural strength (N / mm2)

F = maximum load at break (N)

LS = distance between abutments (h x 18) (mm)

L = applied F / 2 Distance between forces (Ls / 3) (mm)

b = specimen width (mm)

h = sample thickness (mm)

Em = Flexural modulus (N / mm2)

L1 = Distance between the reference axes (mm)

b = specimen width (mm)

h = specimen height (mm)

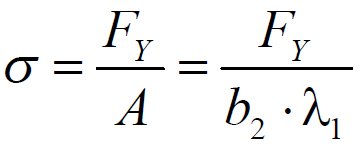
F2-F1 = Load increment in the range of the load displacement diagram (N)

a2-a1 = difference in deflection in the middle of the specimen length due to increased strength (mm)

2.5.3. Tensile shear adhesion strength

All kinds of 10x20x150mm test pieces made of glued wood materials were prepared. The experimental setup was prepared in accordance with the standard established for the samples under study. 3 mm / min in a universal test device. They tried to detach it from the glue line by applying a tensile strength to the adhesion surface at a loading rate.

The following equation was used to calculate the adhesion resistance (σ).



σ = adhesion resistance (N / mm2)

FY = Force at break (N)

λ = length of bonded surface (mm)

b2 = adhesion surface width (mm)

2.5.5. Statistical data evaluation

The SPSS package program was used for the statistical evaluation of the data. Variant analysis was applied to determine if sample types influenced the results. The Dunki, Anov, Friedman, Scheffe and T-test were then applied to the samples to determine the magnitude of the difference between the factors.

3. Conclusions.

3.1 Air Dry Density

The codes of the examples prepared as part of the study and their meanings are shown in Table 1.

**Table 1. Codes used in the study and their meanings**

|  |  |
| --- | --- |
| **Group codes** | **Code Explanation** |
| KE | Epoxy control group |
| KP | Polyurethane control group |
| DE | Epoxy outer surface single layer carbon fiber |
| DP | Polyurethane outer surface single layer carbon fiber |
| AE | Epoxy inner surface single layer carbon fiber |
| AP | Polyurethane inner surface single layer carbon fiber |
| İE | Double layer carbon fiber on the inner surface of Epoxy |
| İP | Double layer carbon fiber on the inner surface of Polyurethane |
| TE | Carbon fiber with double wedge on the outer surface of Epoxy |
| TP | Carbon fiber with double wedge on the outer surface of Polyurethane |

Data on density values according to the measurements made on laminated samples are given in Table 2.

**Table 2.Average values for air-dry densities**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Gruplar** | **Average (g / cm3)** | **Standard deviation** | **Cov value** |
| 1 | KE | 0.486 | 0.013 | 1.91 |
| 2 | KP | 0.449 | 0.008 | 1.72 |
| 3 | DE | 0.541 | 0.021 | 3.70 |
| 4 | DP | 0.521 | 0.006 | 1.12 |
| 5 | AE | 0.479 | 0.006 | 1.17 |
| 6 | AP | 0.469 | 0.012 | 2.47 |
| 7 | İE | 0.518 | 0.020 | 2.29 |
| 8 | İP | 0.484 | 0.002 | 0.47 |
| 9 | TE | 0.501 | 0.016 | 2.79 |
| 10 | TP | 0.469 | 0.008 | 1.76 |

As a result of the experiments, the highest air-dry density was obtained in the epoxy outer surface CFRP coated samples, 0.54 g / cm3, and the lowest density in samples laminated with polyurethane (control) was 0.449 g / cm3.

3.2. Static Bending Strength

Descriptive statistical values of experimental groups are shown in table 3.

Table 3. Descriptive Statistical Values of Experiment Groups

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Group | Standard deviation | Standard error | Coefficient of variation (Cov) | Degrees of freedom | 95% Confidence Interval | | Minimum | Maximum |
| Lower Limit | Upper Limit |
| KE | 9,39 | 5,42 | 24,4 | 2 | 15,04 | 61,74 | 32,52 | 49,23 |
| KP | 3,13 | 1,80 | 9,08 | 2 | 26,69 | 42,26 | 31,03 | 37,15 |
| DE | 7,08 | 4,09 | 9,61 | 2 | 56,01 | 91,21 | 66,67 | 80,92 |
| DP | 8,00 | 4,61 | 12,94 | 2 | 41,99 | 81,74 | 55,02 | 70,63 |
| AE | 9,05 | 5,22 | 14,1 | 2 | 41,68 | 86,67 | 55,49 | 73,56 |
| AP | 6,25 | 3,61 | 10,40 | 2 | 44,39 | 75,47 | 55,60 | 67,11 |
| İE | 9,65 | 5,52 | 24,11 | 2 | 16,03 | 64,01 | 33,10 | 51,05 |
| İP | 12,15 | 7,01 | 10,33 | 2 | 5,24 | 65,64 | 24,58 | 48,57 |
| TE | 6,37 | 3,68 | 10,22 | 2 | 47,18 | 78,86 | 56,51 | 69,26 |
| TP | 3,17 | 1,83 | 5,38 | 2 | 50,99 | 66,77 | 57,01 | 62,55 |

As can be seen from the data at 95% confidence level, the most change was seen in the CFRP groups applied to the outer surfaces in the epoxy and polyurethane groups. According to the elasticity of CFRP, it was observed that the data increased as the length measurements of the samples increased. In order to determine the amount of change between groups, normality test was performed together with Anova and Duncan tests.

**Chart 4. Variance analysis data of experiment groups**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Groups | Smirnov test data | | Shapiro wilk  Test date | | T-value | Variance  value | Kareler  Ortalaması | F value | P value  (P≤0,05) |
| Statistics  Value | Skew value | Statistics value | Importance  Value |
| KE | 0,368 | 1,026 | 0,791 | 0,093 | 8,48 | 0,956 | 88,33 | 176,66 | 0,05 |
| KP | 0,264 | -1,496 | 0,954 | 0,589 | 8,68 | 0,806 | 9,82 | 19,64 | 0,04 |
| DE | 0,193 | 1,415 | 0,997 | 0,891 | 5,22 | 0,790 | 50,21 | 100,42 | 0,05 |
| DP | 0,263 | 1,250 | 0,955 | 0,592 | 9,71 | 0,928 | 64,01 | 128,02 | 0,01 |
| AE | 0,197 | -1,176 | 0,996 | 0,874 | 5,89 | 0,939 | 82,00 | 164,00 | 0,02 |
| AP | 0,342 | 1,606 | 0,845 | 0,228 | 19,69 | 0,852 | 39,11 | 78,22 | 0,02 |
| İE | 0,331 | 0,855 | 0,864 | 0,279 | 9,86 | 0,971 | 93,26 | 186,52 | 0,06 |
| İP | 0,240 | 1,473 | 0,974 | 0,691 | 33,45 | 0,822 | 147,78 | 295,56 | 0,03 |
| TE | 0,184 | -1,500 | 0,999 | 0,928 | 7,71 | 0,852 | 40,65 | 81,30 | 0,09 |
| TP | 0,380 | 1,500 | 0,761 | 0,025 | 10,43 | 0,809 | 10,09 | 20,18 | 0,05 |

The distribution of data among single layer polyurethane groups applied to inner layers does not meet this requirement. The double layer CFRP group of the epoxy group applied to the outer surfaces has the highest homogeneous value data.

3.3. Modulus of elasticity

The descriptive statistical values of the elasticity modulus of the experimental groups are shown in table 5.

**Table 5. Statistical analysis of the elastic modulus of the experimental groups.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Group | Standard deviation | Standard error | Coefficient of variation (Cov) | Degrees of freedom | 95% Confidence Interval | | Minimum | Maximum |
| Lower Limit | Upper Limit |
| KE | 1932,32 | 1115,63 | 21,71 | 2 | 4096,40 | 13696,80 | 7241,20 | 11019,94 |
| KP | 1270,02 | 733,39 | 14,86 | 2 | 5387,70 | 11698,80 | 7079,85 | 9361,18 |
| DE | 6742,15 | 4608,32 | 35,43 | 2 | 6543,55 | 33121,46 | 7860,42 | 22457,57 |
| DP | 960,08 | 3892,70 | 6,42 | 2 | 2277,54 | 35775,48 | 11806,62 | 25159,23 |
| AE | 2902,37 | 1675,68 | 29,71 | 2 | 2541,17 | 16960,96 | 6584,67 | 12285,16 |
| AP | 709,22 | 409,34 | 7,26 | 2 | 7994,36 | 11516,88 | 8940,77 | 10231,58 |
| İE | 3116,04 | 1904,07 | 34,02 | 2 | 783,10 | 17173,63 | 5875,95 | 12443,97 |
| İP | 2514,25 | 318,13 | 28,92 | 2 | 2288,76 | 5026,45 | 3156,50 | 4247,73 |
| TE | 7982,02 | 554,75 | 60,05 | 2 | 1257,13 | 1734,90 | 13851,32 | 15550,37 |
| TP | 1215,81 | 1215,80 | 13,92 | 2 | 5713,70 | 11754,13 | 7384,52 | 9774,05 |

The results of the tests performed to determine the difference between the groups are shown in Table 6.

**Table 6. Variance elasticity modulus analysis data of the experimental groups**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Groups | Smirnov test data | | Shapiro wilk  Test date | | T-value | Variance  value | Kareler  Ortalaması | F value | P value  (P≤0,05) |
| Statistics  Value | Skew value | Statistics value | Importance  Value |
| KE | 1,620 | 0,231 | 0,980 | 0,732 | 11,497 | 3733943,04 | 8420,20 | 1,914 | 0,072 |
| KP | 1,722 | 0,361 | 0,917 | 0,806 | 26,96 | 1613608,40 | 7963,07 | 1,220 | 0,001 |
| DE | 1,114 | 0,347 | 0,836 | 0,204 | 2,88 | 6370991,24 | 11401,68 | 1,960 | 0,002 |
| DP | 1,524 | 0,262 | 0,956 | 0,596 | 23,83 | 4545951,18 | 9685,05 | 1,874 | 0,002 |
| AE | 1,886 | 0,253 | 0,924 | 0,964 | 5,81 | 8423767,36 | 11209,93 | 1,634 | 0,028 |
| AP | 1,741 | 0,350 | 1,00 | 0,829 | 12,44 | 502685,892 | 10196,21 | 1,882 | 0,006 |
| İE | 1,700 | 0,350 | 0,829 | 0,185 | 4,71 | 1088364,93 | 11172,76 | 1,765 | 0,051 |
| İP | 1,462 | 0,231 | 0,980 | 0,732 | 11,64 | 1561056,37 | 9157,76 | 1,880 | 0,007 |
| TE | 1,602 | 0,231 | 0,916 | 0,980 | 4,88 | 2504333,71 | 10232,64 | 1,901 | 0,039 |
| TP | 1,554 | 0,277 | 0,942 | 0,534 | 7,97 | 1478171,54 | 9488,28 | 1,336 | 0,015 |

In a similar study by Ç.Altay, the elasticity modulus in bending was determined mostly in samples (14004,83 N / mm2) obtained by coating epoxy between layers and CFRP around it. CFRP material increases the elasticity of the laminated wood material and makes it hard.

3.4. Adhesion Strength Tensile Shear Test

The preliminary processes performed on the experimental groups are shown in table 7.

**Table 7.Pre-treatments applied for the adhesion (tensile-shear) test**

|  |  |
| --- | --- |
| Operation code | Pre-treatment |
| A1 | Testing immediately after conditioning in standard atmosphere \* 7 days |
| A2 | Immersion in 20 ± 5 ° C water for 4 days and testing in wet conditions |
| A3 | Immersion in 20 ± 5 ° C water for 4 days  Reconditioning and dry testing to its original weight \*\* under standard atmospheric conditions |
| A4 | 6 hours immersion in boiling water, 2 hours immersion in 20 ± 5 ° C water and wet test |
| A5 | 6 hours immersion in boiling water, 2 hours immersion in 20 ± 5 ° C water  Reconditioning to its original weight and dry test in standard atmospheric conditions |

\* Standard atmospheric conditions are 20 ± 2 ° C temperature and 65% ± 5 relative humidity conditions.

\*\* The tolerance for the original weight is + 2% and -1%.

The analysis of variance data on the adhesion resistance tests are shown in table 8.

**Table8. Analysis of variance for adhesion resistance**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variance Source | **Sum of Squares** | **Degrees of freedom** | **F value** | **P value** |
| Interaction | 441,25 | 1 | 463,25 | 0,00 |
| Glue | 19,85 | 1 | 19,20 | 0,00 |
| Glue x CFRP | 19,85 | 1 | 19,20 | 0,00 |

According to the results of variance analysis, it was determined that the effect of interaction, glue and glue CFRP interactions on adhesion resistance was significant at 95% confidence interval. Duncan test results belonging to them are given in Table 9.

**Table 9.Duncan test in groups belonging to adhesion experiment**

|  |  |  |
| --- | --- | --- |
| Sample Type | Average Value (N / mm2) | Homogeneity Group |
| CFRP + Epoxy | 115,40 | A |
| Epoxy surround CFRP | 118,20 | B |
| Polyurethane around CFRP | 104,11 | AB |
| Epoxy (Control) | 101,12 | C |
| Polyurethane (Control) | 83,72 | CD |

Polyurethane and epoxy adhesive samples were found in the same homogeneity group according to the duncan test. The glue type samples used while creating the laminate samples did not show any effect on the laminate samples without CFRP.

4. Results

According to the results of the experiment, the highest density was seen in the single layer CFRP group around the epoxy 0.521 g / cm3. According to the experimental results, the static bending resistance of the samples was obtained at most (73,324 N / mm2) in laminated samples in which a single layer of CFRP building material and epoxy adhesive were used, and it increased by 26% compared to the control groups. In the wood industry, carbon fiber reinforced composites can be used together with epoxy adhesive to strengthen the parts of the wood material exposed to bending.

The average value of elastic modulus in bending was determined in the samples obtained by covering the epoxy with CFRP with maximum 11831,797 N / mm2 and it increased by 24.31% compared to the control groups. It can be used in regional strengthening of wooden bridges, stairs, columns, beams and roofs of CFRP building material thanks to its high stretch and break feature.

As a result of the adhesion test, it was determined that the average adhesion resistance was the highest (19.85 N / mm2) in the sample types laminated with CFRP building material and Epoxy adhesive between layers. At the same time, it increased by 101.89% compared to the control groups. Therefore, it can be used for strengthening the damaged parts of wooden structures and restoration works by using CFRP and epoxy adhesive.

As a result, using carbon fiber material and epoxy adhesive, wooden columns, beams, etc. It can be used to reinforce structural elements. Carbon fiber can be preferred in wooden structure sections due to its high elasticity and breakage properties. In addition, it can be used to extend the wear time, especially on wooden floors, thanks to the strong and fast penetration of the epoxy to the applied surface and its increased strength with carbon fiber.

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