Properties of Composite Laminated Material Produced with Layers of Beech and Paperboard Made from Waste Paper

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ABSTRACT: One of the basic principles for sustainable development is to prevent wasting resources, preserve natural resources, and recycle the products obtained from resources. For this study, paperboard obtained from waste paper was laminated with natural wooden layers in accordance with the order of beech-paperboard-beech-paperboard-beech and an alternate material was produced. In this context, experiments were made for determining the specific gravity, compression, shearing, bending strength, elasticity module, and the resistance to direct withdrawal of screws and nails on a radial section surface with the objective of determining the usability of this material as a building material. When the findings obtained at the end of the experiments are studied carefully in a comparative manner, it was observed that paperboard laminated materials could be used with different objectives in interiors to protect against humidity. It was determined that it could be used in place of solid poplar materials for places of use where resistance to compression, elasticity module, and resistance to direct withdrawal of screws and nails on a radial section surface are important and in places where resistance to bending and shearing is required after taking the necessary measures. In the end, a contribution to the literature was provided by researching possibilities for different use of a material regained from waste and to provide sustainability. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 101: 1943–1952, 2006

Key words: waste paper; paperboard; lamination; beech; poplar; specific gravity;

INTRODUCTION

For a sustainable development, it is a necessity to use renewable resources to preserve resources and to develop regaining strategies. The forest resources are in the lead of the renewable resources. As in the entire world, in Turkey as well, the forests are not increasing in parallel with the needs. For this reason, a shortage of materials is arising for the wood and paper industry. In this connection, studies are being done on the subject of using wood wisely and recycling waste paper. Particularly studies done for recycling newsprint without being processed and purifying it of printer's ink are rather noteworthy.[1,2] In these studies, it is stated that waste paper can be utilized in the direct production of panels or in the production of panels by mixing it with wooden fibers and chips. It is observed that many varieties of paper types, after being broken down and transformed into fibers, can be attached with organic and inorganic glues and the production of paperboard panels, medium density fiberboard, and new materials can be realized and that these materials can find an area of use in various sectors.[3,4]

In parallel with these studies, it is also observed that performance-based studies have been made on composite panels produced by using wood and paper. In this connection, it is observed that waste polypropylene and polyethylene glues can be utilized with the objective of acquiring a water repellent attribute to composites in the form of panels.[5,6] In case waste paper and wooden chips are each used at the ratio of 50%, and in case the amount of phenolic resin is increased, then the density will also increase and all of the attributes of the panel would improve.[7] In case it is attached with isocyanate, then it could increase the resistance to the direct withdrawal of nails and screws and it can be shaped with heat.[3] According to another result obtained from the studies made, it was observed that the distribution of paper within the plastic matrix and the strength of the bonding of wood with paper were influential on the physical and mechanical properties.[8]

In the studies made on the panels obtained from a mixture of waste paper and wood, composites are

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TABLE I
Descriptive Statistical Values for the Dry Air Specific Gravity Values

Type of material	Number of specimens	Average value (g/cm^3)	Minimum value (g/cm^3)	Maximum value (g/cm^3)	Standard deviation (g/cm^3)
Solid beech	20	0.71	0.67	0.75	0.02
Solid poplar	20	0.41	0.37	0.42	0.01
Beech-paperboard laminated material	20	0.74	0.70	0.77	0.02

TABLE II
Results of the Analysis of Variance (ANOVA) Among the Dry Air Specific Gravity Values

Source of variance	Sum of squares	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	1.36	2	0.68	1,937.23	0.000*
Within group	0.02	57	0.00		
Total	1.38	59			

formed after breaking down the paper and wood by mechanical means and combining them with a different binder. Studies made on the materials in which paper that is made into a panel and wood are joined in a laminated character have not been encountered. Although provided that it is used in interiors, it is possible to obtain a composite material with more different methods.

In this connection, in this study, the beech layers are laminated together with paperboard obtained from waste papers and a new composite laminated material is obtained and some properties of this material are compared with "solid beech," "solid poplar," and "beech-poplar laminated composite board " and it is attempted to determine the usability properties of the new material.

EXPERIMENT

Wood, paperboard, and polyvinyl acetate (PVAc) glue were used in the test specimens produced to be used in the study.

Materials

Wood

Beech trees (*Fagus orientalis Lipsky*), which are grown naturally in Mengen, Bolu, and Poplar trees (*Populus nigra*), from Beytepe, Ankara, are used in the experiments, were obtained by cutting them according to ISO 4471.[9]

Paperboard

The paperboard used as a laminated layer in the study was obtained from the Meteksan Corp. The paperboard is obtained completely from waste papers and has an average thickness of 3.20 mm and an average weight of 2620 g/m^2.[10]

Glue

In the study, polyvinyl acetate (PVAc) glue was used, which has the D3 adhesion quality as a single component according to BS EN 204, in the gluing of the laminated layers, and having the quality D4 EN 204 when a 5% turbo hardener is added, for the building materials according to the data of the manufacturing company. The recommendations of the manufacturing company were complied with in the storage and use of the material.[11]

TABLE III
Results of the Duncan Test

Type of material	Number of specimens	$\alpha = 0.05$		
		1	2	3
Solid poplar	20	0.41		
Solid beech	20		0.71	
Beech-paperboard laminated material	20			0.74

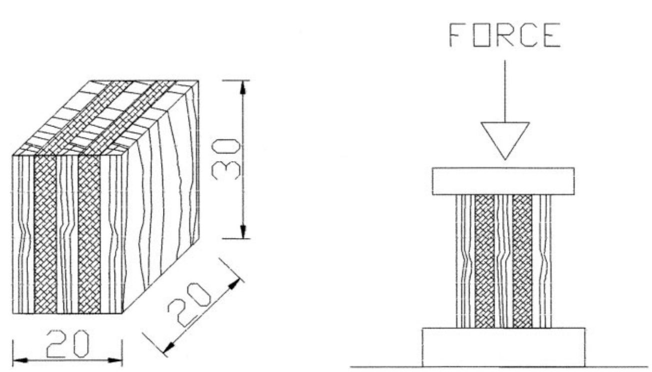

Figure 1 Test specimen and test method for measuring resistance to compression in a direction parallel to the grain.

TABLE IV
Descriptive Statistical Values for the Resistances to Compression

Type of material	Number of specimens	Average value (N/mm^2)	Minimum value (N/mm^2)	Maximum value (N/mm^2)	Standard deviation (N/mm^2)
Solid beech	20	71.59	63.62	84.42	5.23
Solid poplar	20	46.13	38.83	52.39	3.42
Beech-paperboard laminated material	20	53.13	45.05	60.26	3.63

TABLE V
Results of the Analysis of Variance (ANOVA) Among the Resistance to Compression Values

Source of variance	Sum of squares.	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	6,917.71	2	3,458.86	198.59	0.000*
Within group	992.78	57	17.42		
Total	7,910.49	59			

Method and findings

Preparation of the test specimens

The pieces of lumber, which were dried to a 12% dry air level of humidity, were cut to the measurements of $5 \times 50 \times 450$ mm^3. Subsequently, the pieces were sanded with a calibrated sander with a No. 60 sander on both surfaces until they reached a thickness of 4 mm. The principles in the TS EN 310 (EN 310)[12] were taken into consideration in the determination and preparation of the dimensions of the specimens. PVAc glue was applied to the single surfaces of the pieces prepared at 160 g/m^2 according to the suggestion of the manufacturing company. The glued pieces were put one on top of the other in 5 layers and in the sequence of beech-paperboard-beech-paperboard-beech and were pressed for 5 min at a pressing pressure of 1 N/mm^2 at a pressing temperature of (50 $\pm$ 1)°C. The pieces coming out from the press having the dimensions of $20 \times 50 \times 45$ mm^3 were prepared as shearing resistance test specimens, those having the dimensions of $20 \times 20 \times 30$ mm^3 were prepared as the specific gravity and resistance to compression test specimens and those having the dimensions of $20 \times 20 \times 360$ mm^3 were prepared as the bending and elasticity module test specimens. Twenty specimens from each test specimen for a total of 100 each specimens were pressed in the dimensions given above. One hundred solid beech and 100 solid poplar test specimens in the same dimensions were prepared as the control specimens.

The test specimens prepared were kept in a climatization room having a relative humidity of (65 $\pm$ 5)% and a temperature of (20 $\pm$ 2)°C until the weight did not change (until the humidity dropped to 10%), with the objective of homogenization of the humidity volume-wise prior to the test. Later, the specimens were insulated to prevent a loss of humidity and were kept for the test.

The F test was used in the study to determine the effects of the three different wood materials on the specific gravity, compression, shearing, bending resistances, elasticity modules, and the resistance to direct withdrawal of the screws and nails on the radial section surfaces. In case the difference among the groups turned out to be significant, a comparison was made with the Duncan test at the $\alpha = 0.05$ confidence level. According to this, it was determined that there was a

TABLE VI
Duncan Test Results

Type of material	Number of specimens	α=0.05 1	2	3
Solid beech	20	46.13		
Solid poplar	20		53.14	
Beech-paperboard laminated material	20			71.59

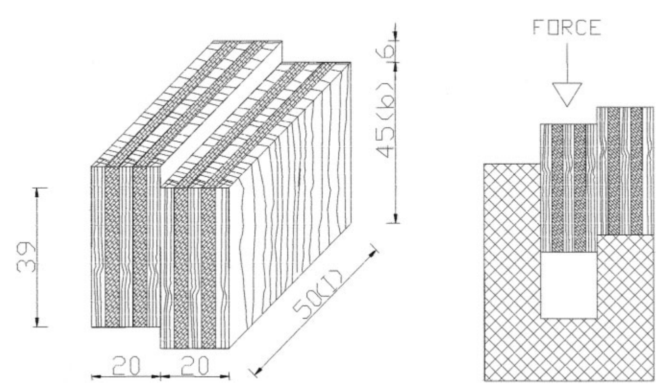

Figure 2 Experimental specimen and experimental method in the resistance to shearing in a parallel direction to the grain.

TABLE VII
Descriptive Statistical Values for the Resistances to Shearing

Type of material	Number of specimens	Average value (N/mm²)	Minimum value (N/mm²)	Maximum value (N/mm²)	Standard deviation (N/mm²)
Solid beech	20	14.38	11.50	16.58	1.47
Solid poplar	20	10.02	9.40	10.73	0.46
Beech-paperboard laminated material	20	2.53	1.52	4.30	0.84

level of significance of $\alpha = 0.05$ among the material combinations used in each test, that there was a difference of 95% in reliability, and that this difference was significant ($P < 0.05$). The Duncan test was applied to determine among which groups there was a difference and the test results were shown in the tables. The SPPS 11.5 package program was used in the calculations of the Analysis of Variance (ANOVA), arithmetic average, standard deviation, standard error, and the minimum and maximum values.[13]

Dry air specific gravity values

Specific gravity is an important characteristic, which gives an idea about the possibilities for usage of a material. A material, which has a high specific gravity, has greater resistance, flexibility, and hardness compared to those with a lower specific gravity and its strength to resist corroding factors is high. In this connection, in wood based materials as well, the softness of the wood increases as the specific gravity decreases, it becomes easier to process and workability decreases. For this reason, this characteristic can be an important indicator in the determination of the place of use of the material.

The determination of the dry air specific gravity was made according to TS 2472 (ISO 3131).[14] Twenty test specimens prepared in the dimensions of $20 \times 20 \times 30$ mm^3 were used in this determination. These specimens were kept for a period of one month in a climatization room having a temperature of (20 ± 2)°C and a relative humidity of (65 ± 5)% and it was provided that they came to the dry air humidity level. The test specimens were weighed on an electronic scale with a sensitivity of 0.01 g and their dimensions were measured with a digital compass having 1/100 mm sensitivity. Equation (1) was used in the calculation of the dry air specific gravity:

$$D_{12} = \frac{M_{12}}{V_{12}} \tag{1}$$

where D_{12} is the dry air specific gravity (g/cm^3), M_{12} is the dry air weight of the test specimen (g), and V_{12} is the dry air volume of the test specimen (cm^3).

The dry air specific gravity values obtained at the end of the tests are given in Table I. According to the table, the highest dry air specific gravity value was 0.74 g/cm^3 in the laminated material, the lowest dry air specific gravity value was 0.41 g/cm^3 in the solid poplar material, and it was determined that the dry air specific gravity was 0.71 g/cm^3 in the solid beech material, which is between these two values.

The results of the F test related to the dry air specific gravity of the materials are given in Table II and the results of the Duncan test are given in Table III.

Resistance to compression in a direction parallel to the grain

Resistance to compression is the reaction of a material or element shown against forces aimed at compression and crushing. All components, division panels, furniture feet, etc. lying in a perpendicular position in a structure are under the influence of a compression load. The test given below was made with the objective of determining the resistance of the material.

The experiments were made in the 4-ton universal test machine in conformance with the procedure indicated in TS 2595 (ISO 3798)[15] (Fig. 1). A fixed loading was made on the crosscut surface of the specimens that would crush the specimens within 1.5–2 min. The

TABLE VIII
Analysis of Variance (ANOVA) Results Among the Resistance to Shearing Values

Source of variance	Sum of squares	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	1,438.76	2	719.38	705.78	0.000*
Within group	58.10	57	1.02		
Total	1,496.86	59			

TABLE IX
Duncan Test Results

Type of material	Number of specimens	$\alpha = 0.05$ 1	2	3
Solid beech	20	10.02		
Solid poplar	20		2.53	
Beech-paperboard laminated material	20			14.38

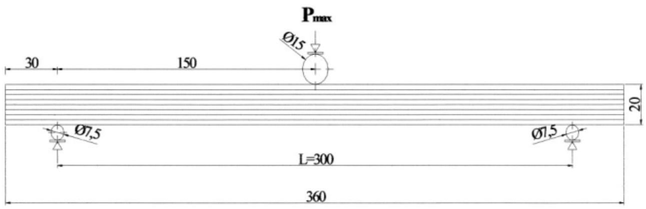

Figure 3 Experimental mechanism to measure resistance to bending and elasticity module.

loading application was continued until the specimens were broken and the maximum loads at the moment of breakage were read on the indicator of the machine. Equation (2) was used in the calculation of the resistance to compression.

$$\sigma = \frac{P_{\max}}{A} \tag{2}$$

where σ is the resistance to compression (N/mm^2), $P_{\max}$ is the maximum load (N), and A is the surface area subjected to compression (mm^2).

The descriptive statistical values for the resistances to compression obtained at the end of the experiments are given in Table IV. According to the Table, it was determined that the maximum compression value was obtained in solid beech at 71.59 N/mm^2, the minimum compression value was obtained in solid poplar at 46.13 N/mm^2, and that the compression value of the paperboard laminated material was between these two values at 53.13 N/mm^2.

The results of the F test related to the compression resistance values of the materials are given in Table V and the results of the Duncan test are given in Table VI.

Resistance to shearing in a direction parallel to the grain

Resistance to shearing is a characteristic showing the resistance at the joining places of the components or resistance capacity shown by the material against the forces trying to cut it. The experiment for which the procedure is given below was made with the objective of determining the resistance the materials could show against this. The experiments were realized in the 4-ton universal wood material test machine in accordance with the ASTM D 3110 standards.[16] The test materials were placed in the test machine in the manner shown in Figure 2 and the load was applied that would make a shearing effect. The machine loading speed was adjusted to 12.7 mm/min during the experiment. It was operated in a manner so that the layer of glue would be broken within 1.5–2 min and the maximum load at the moment of breakage was determined. Equation 3 was used in the calculation of the resistance to shearing.

$$\sigma_M = \frac{P_{\max}}{A} \tag{3}$$

where ó is the resistance to shearing (N/mm^2), $P_{\max}$ is the breaking load (N), and A is the glued surface area (mm^2).

The descriptive statistical values for the resistance to shearing of the materials are given in Tables VII and VIII. According to this, the maximum resistance was determined to be in beech at 14.38 N/mm^2 and this was followed in poplar at 10.02 N/mm^2. The minimum resistance was in laminated materials at 2.53 N/mm^2.

The results of the F test related to the resistance to bending of the materials and the results of the Duncan test are given below (Table IX).

Bending resistance in a direction perpendicular to the grain

In case any material or building element exceeds the space between supports, for example, the surfaces of a table or chair, then they are subjected to bending. In case the experimental specimen remains under such an influence, then experiments were made in accordance with the TS EN 310 (EN 310) standards[12] with the objective of determining the resistance against bending.

The computer-controlled 100 kg capacity universal test equipment was used for the experiments. The specimens were placed in the test equipment as shown in Figure 3. A loading was made in a manner that would break the specimen in 90 ± 0.5 s with a fixed

TABLE X
Descriptive Statistical Values for the Resistance to Bending

Type of material	Number of specimens	Average value (N/mm^2)	Minimum value (N/mm^2)	Maximum value (N/mm^2)	Standard deviation (N/mm^2)
Solid beech	20	132.06	108.37	151.27	13.47
Solid poplar	20	74.80	56.89	88.84	9.52
Beech-paperboard laminated material	20	41.02	31.06	48.73	6.40

TABLE XI
Analysis of Variance (ANOVA) Among the Resistance to Bending Values

Source of variance	Sum of squares	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	84,717.97	2	42,358.99	406.02	0.000*
Within group	5,946.71	57	104.33		
Total	90,664.68	59			

speed and the load (P_{max}) at the moment of breaking was determined and recorded. The resistances were determined by placing the values obtained in eq. (4).

$$\sigma = \frac{3P_{max}1}{2bh^2} \quad (4)$$

where σ is the bending resistance (N/mm^2), P_{max} is the breaking load (N), L is the space between supporting points (mm), b is the width of the specimens (mm), and h is the height of the specimens (mm).

The maximum resistance to bending of the materials was determined in solid beech at 132.06 N/mm^2 and this was followed by solid poplar at 74.80 N/mm^2. The minimum resistances to bending were determined in paperboard laminated materials at 41.02 N/mm^2 (Table X).

The results of the F test related to the resistance to bending of the materials are given in Table XI and the results of the Duncan test are given in Table XII.

The elasticity module in bending perpendicularly to the grain

The recovery of the deformation, which occurs in the materials at the moment of removing the forces applied from outside onto a hard object, is called elastic deformation. As the elasticity module increases, the objects display a higher resistance against forces, which cause deformation and as the elasticity module decreases, the objects change form more easily.

Experiments for the determination of the elasticity module were made according to the principles of TS EN 310 (EN 310).[12] The equation below is utilized in the determination of the elasticity module with the assistance of the difference in bending amounts (Δf) for the difference in force applied to the area of deformation (ΔF):

$$E = \frac{\Delta F I^3}{4bh^2\Delta f} \quad (5)$$

where E is the elasticity module in bending (N/mm^2), L is the distance between supports (mm), b and h are the width of cut dimensions of the specimens (mm).

The descriptive statistical values for the elasticity modules of the experimental specimens are given in Table XIII. The highest elasticity module value was determined in the beech materials at 12,856.16 N/mm^2, followed by the laminated materials at 8718.66 N/mm^2, and the lowest elasticity module value was determined in the poplar materials at 7551.47 N/mm^2.

The results of the F test related to the elasticity modules of the materials are given in Table XIV and the results of the Duncan test are given in Table XV.

Resistance to direct withdrawal of screws at the radial section surface

The strength of any building system, which is formed with the joining of elements, is dependent on the performance of the fastenings, which hold the pieces together. Nails and screws are the mechanical fasten-

TABLE XII
Duncan Test Results

Type of material	Number of specimens	$\alpha = 0.05$ 1	2	3
Solid beech	20	74.80		
Solid poplar	20		41.02	
Beech-paperboard laminated material	20			132.06

TABLE XIII
Descriptive Statistical Values for the Elasticity Modules

Type of material	Number. of specimens	Average value (N/mm^2)	Minimum value (N/mm^2)	Maximum value (N/mm^2)	Standard deviation (N/mm^2)
Solid beech	20	12,856.16	10,814.63	15,739.10	1,470.89
Solid poplar	20	7,551.47	5,725.75	9,089.97	929.99
Beech-paperboard laminated material	20	8,718.66	7,799.00	9,605.71	680.71

TABLE XIV
Analysis of Variance (ANOVA) Results Among the Elasticity Module Values

Source of variance	Sum of squares	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	310,806,083.08	2	155,403,041.54	133.52	0.000*
Within group	66,343,639.76	57	1,163,923.51		
Total	377,149,722.84	59			

ings, which are used extensively in the connections of solid and laminated wood elements. Knowing the resistance to direct withdrawal of screws and nails of the wood building elements gives information on the strength and stability of the system. Furthermore, it is important to know the resistance to direct withdrawal of screws and nails to be able to use the materials productively and effectively. For this reason, the resistance to direct withdrawal of the screws and nails of the experimental specimens were determined. Two screws (22 × 50) were screwed into the lead holes previously opened on the radial section surface of the experimental specimen in a manner in which they enter into a 35 mm portion and perpendicular to the surface of the specimens, which were prepared according to the ASTM D 1761 standards.[17] The screwing onto the solid poplar and beech specimens were also made in the same manner (Fig. 4).

TABLE XV
Duncan Test Results

Type of material	Number of specimens	$\alpha = 0.05$ 1	2	3
Solid beech	20	7,551.00		
Solid poplar	20		8,719.00	
Beech-paperboard laminated Material	20			12,856.00

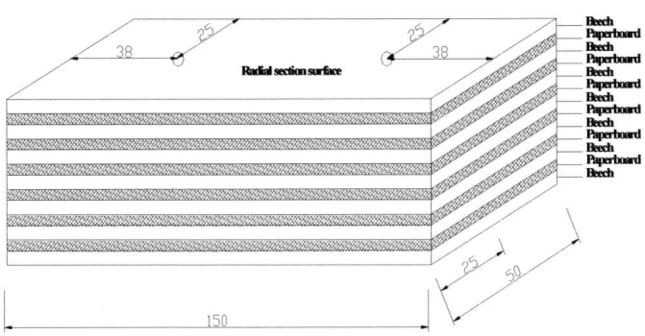

Figure 4 The screwing and nailing plan for the experimental specimens.

The experiments were realized by placing the experimental specimens in the universal test machine in a manner in conformance with the ASTM D 1761 standards. During the experiment, a withdrawal speed of 2.5 mm/min was applied until the screws were completely removed. The results for 20 specimens were read and recorded for every experiment.

The descriptive statistical values for the resistance to direct withdrawal of screws of the experimental specimens are given in Table XVI. The maximum resistance to direct withdrawal value of the screws was determined in the beech material at 5373.00 N and in the laminated material at 3235.00 N. The minimum resistance to direct withdrawal value of the screws was determined in the poplar material at 2584.00 N.

The results of the F test related to the resistance to direct withdrawal values of the materials are given in Table XVII and the results of the Duncan test are given in Table XVIII.

Resistance to direct withdrawal of nails at the radial section surface

A total of 2 round cross-sectioned steel nails in accordance with TS 155 (DIN 1157)[18] having a diameter of 2.67 mm and a length of 50 mm, and the surface of which were not covered with any substance, were nailed into the climatized experimental specimens in a manner in which a 35 mm portion entered into the material. The hammering system was applied like that of the screwing (Fig. 4) and a fixed resistance to direct

TABLE XVI
Descriptive Statistical Values for the Withdrawal Strength Values of Screws

Type of material	Number of specimens	Average value (N)	Minimum value (N)	Maximum value (N)	Standard deviation (N)
Solid beech	20	5,373.00	4,280.00	6,400.00	635.88
Solid poplar	20	2,584.00	1,680.00	3,960.00	594.45
Beech-paperboard laminated material	20	3,235.00	2,540.00	3,800.00	465.52

TABLE XVII
Analysis of Variance (ANOVA) Results Among the Resistance to Direct Withdrawal the of Screws

Source of variance	Sum of squares	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	85,155,773.33	2	42,577,886.67	131.09	0.000*
Within group	18,514,200.00	57	324,810.53		
Total	103,669,973.33	59			

withdrawal of 2 mm/min was applied to the specimens until the nails were removed and the maximum strength at the moment the nail was removed was read from the dial of the machine and recorded. The resistance to direct withdrawal of the nails was also calculated in a manner similar to the resistance to direct withdrawal of the screws.

The descriptive statistical values of the resistance of the experimental specimens to direct withdrawal value of the nails are given in Table XIX. The maximum resistance to direct withdrawal value of the nails was determined in beech material at 1447.00 N and in laminated material at 1227.00 N. The minimum resistance to direct withdrawal of the nails was determined in poplar material at 580.00 N.

The results of the F test related to the resistance to direct withdrawal values of the nails from the materials are given in Table XX and the results of the Duncan test are given in Table XXI.

TABLE XVIII
Duncan Test Results

Type of materials	Number of specimens	$\alpha = 0.05$		
		1	2	3
Solid poplar	20	2,584.00		
Beech-paperboard laminated materials	20		3,235.00	
Solid beech	20			5,373.00

RESULTS AND DISCUSSION

The mechanical properties determined at the end of the experiments on solid beech, solid poplar and laminated materials are given in Tables XXII and XXIII. The values for the Beech-Poplar laminated materials shown in the tables were taken from another study made with the objective of determining the performance of five-layered laminated materials (PVAc4) manufactured by using PVAc glue.[19]

At the conclusion of the study, it was found that the specific gravity of the beech-paperboard laminated material was higher than that of solid beech, solid poplar, and beech-poplar laminated material. The use of paperboard in the beech-paperboard laminated material caused the specific gravity to increase. The surface of the material in the upper layers strengthened against corrosive effects with the use of beech, which has a higher specific gravity.

At the conclusion of the experiments, it was found that the compression resistance of the beech-paperboard laminated material was lower than solid beech and higher than solid poplar. It was observed that it could be an alternative to the laminated material, which is prepared with a beech-poplar combination. It

TABLE XIX
Descriptive Statistical Values of the Resistance to Direct Withdrawal Values of the Nails

Type of materials	Number of specimens	Average value (N)	Minimum value (N)	Maximum value (N)	Standard deviation (N)
Solid beech	20	1,447.00	1,000.00	1,800.00	193.07
Solid poplar	20	580.00	420.00	820.00	102.19
Beech-paperboard laminated material	20	1,227.00	1,040.00	1,380.00	101.83

TABLE XX
Analysis of Variance (ANOVA) Results Among the Resistance to Direct Withdrawal Values of the Nails

Source of variance	Sum of squares	Degrees of freedom	Mean square	F	Significance ($P < 0.05$)
Among groups	8,124,653.33	2	4,062,326.67	209.81	0.000*
Within group	1,103,640.00	57	19,362.11		
Total	9,228,293.33	59			

TABLE XXI
Duncan Test Results

Type of materials	Number of specimens	α = 0.05		
		1	2	3
Solid poplar	20	580		
Beech-paperboard laminated material	20		1,227	
Solid beech	20			1,447

is clearly observed that in situations where materials remain under the influence of compression resistance in interiors, the beech-paperboard laminated material could be used in place of the solid poplar material.

In the study, the resistance to shearing of the laminated material was significantly lower compared with the results obtained from solid beech and solid poplar. The reason for this is the breakages occurring in the internal structure of the paperboard in response to a load applied parallel to the grain. When a load is applied, the breakage is a breakage within itself, not on the glueline where the paperboard and beech are joined. For this reason, it can be said that the beech-paperboard laminated material is not suitable for places, which require resistance to shearing, and that it is necessary not to place them in constructions in a manner in which they would be subjected to resistance to shearing parallel to the grain. However, it is possible to form a panel in case it is used together with another material, which could withstand the shearing forces.

In the study, the resistance to bending of the laminated materials were found to be rather lower than that of the beech and poplar materials. The reason for this could be the lack of strength in the internal structure of the paperboard material, just as in the resistance to shearing. When a load is applied to the laminated materials, the paperboard, which is an in-between layer, is breaking within itself. For this reason, laminated material is not suitable for places, which require resistance to bending.

In the study, it was determined that the elasticity module of the laminated material was lower than that of the solid beech and that it was a little bit higher than that of the poplar.

At the conclusion of the experiments, it was determined that the resistance to direct withdrawal of the screws on the radial section surface of the beech-paperboard laminated materials was lower than the solid beech and beech-poplar laminated materials and higher than the solid poplar. Also, in a similar manner, it was found that the resistance to direct withdrawal of the nails on the radial section surface of the beech-paperboard laminated materials was lower than the solid beech and beech-poplar laminated materials and higher than the solid poplar. According to this, it was observed that the beech-paperboard laminated materials could be preferred compared to solid poplar for high resistance to direct withdrawal of screws and nails on radial section surfaces.

TABLE XXII
The Physical and Mechanical Properties Determined at the Conclusion of the Experiments with Solid Beech, Solid Poplar and Laminated Materials (Average Values)

Type of materials	Specific gravity (g/cm^3)	Resistance to compression (N/mm^2)	Resistance to shearing (N/mm^2)	Resistance to bending (N/mm^2)	Elasticity module (N/mm^2)
Solid beech	0.71	71.59	14.38	132.06	12,856.16
Solid poplar	0.41	46.13	10.02	74.8	7,551.47
Beech-poplar laminated materials	0.60	56.77	11.05	97.17	11,530.56
Beech-paperboard laminated materials	0.74	53.13	2.53	41.02	8,718.66

TABLE XXIII
The Resistance to Direct Withdrawal of the Nails and Screws on the Radial Section Surface (Average Values)

Type of materials	Resistance to direct withdrawal of the screws on the radial section surface (N)	Resistance to direct withdrawal of the nails on the radial section surface (N)
Solid beech	5,373.00	1,447
Solid poplar	2,584.00	580
Beech-poplar laminated materials	4,251.00	1,119
Beech-paperboard laminated materials	3,235.00	1,227

CONCLUSIONS

The forests in the world and in Turkey, despite the fact that they are a renewable resource, have decreased to a significant degree and continue to decrease. It appears to be necessary to make studies for providing for the use of forest products both without waste and also for regaining them under all conditions because of the fact that they are a scarce and expensive resource. Especially, in the studies made with the objective of being able to use paper without requiring special processes and to serve different uses, it is observed that composite materials are extensively produced from wood chips and waste paper. It this study, it was attempted to determine the usability of waste paper in the production of new materials with a different technique. For this purpose, the paperboard layers obtained from beech and completely waste paper were laminated and a new composite material was obtained and some properties of this material were compared with solid beach and solid poplar materials.

The findings and comparisons show that paperboard laminated materials could be used with different objectives in interiors to protect against humidity and can find an area of use in various sectors.

References

1. Kinney, R. W. J. Technology for Paper Recycling; Blankie: London, 1995.
2. Clad, W. Holz Roh-Werkstoff 1970, 28, 101.
3. Grigoriou, A. H. Wood Sci and Technol 2003, 37, 79.
4. Davis, F. E. In Proceedings of 30th International Particleboard/Composite Materials Symposium, Pullman, WA 1996, p 73.
5. Ellis, S.; Ruddick, J.; Steiner, P. A. Forest Prod J 1993, 43, 23.
6. Youngquist, J.; Meyers, G.; Muehl, J. H.; Krysic, A. M.; Clemons, C. M. Composites from Recycled wood and Plastics; EPA: Cincinnati, 1994.
7. Krysic, A.; Youngquist, J. A.; Rowell, R. M.; Muehl, J. H.; Chow, P.; Shook, S. R. Forest Prod J 1993, 43, 53.
8. Gerischer, G. Holzforschung 1977, 31, 129.
9. Wood—sampling sample trees and longs for determination of physical and mechanical properties of wood in homogenous stands, ISO 4471, 1982.
10. Meteksan Company Catalogue (2004), http://www.meteksan.com.tr.
11. Kleiberit, Kleiberit 303 Catalogue (2004).
12. Wood based panels determination of modulus of elasticity in bending and of bending strength, TS EN 310, Turkish Standards Institution, 1997.
13. Statistical package for social science, SPSS 11.5, License No. 30731 36090 778423 67348.
14. Wood determination of density for physical and mechanical tests, TS 2472 (ISO 3131),Turkish Standards Institution, 1976.
15. Wood determination of ultimate stress in compression parallel to grain, TS 2595 (ISO 3798), Turkish Standards Institution, 1977.
16. Adhesive used in nonstructural glued lumber products, ASTM D 3110, ASTM International, USA, 1983.
17. Standard methods of testing mechanical fasteners in wood; nail, staple or screw withdrawal test, ASTM D 1761, ASTM International, USA, 2000.
18. Nails, TS 155 (DIN 1157), Turkish Standards Institution, 1978.
19. Celebi, G.; Kilic, M. Determination of performance characteristics of composite laminated building materials produced from beech and poplar, TUBITAK ÍCTAG-671, 2004.