Turkish Journal of Forest Science
Available online at dergipark.gov.tr/turkjforsci

THE EFFECT OF ADHESIVE TYPE AND REINFORCEMENT TYPE ON FLEXURAL DEFORMATION OF BENDING LVL

İlkay ATAR[1,*], Fatih MENGELOĞLU[1]

[1]Faculty of Forestry, Dept. of Forest Industry Engineering, KSÜ, Kahramanmaraş, 46050, Turkey

[*]Corresponding author: iatar@ksu.edu.tr

İlkay AYAR: https://orcid.org/0000-0001-9527-1791
Fatih MENGELOĞLU: https://orcid.org/0000-0002-2614-3662

Please cite this article as: Atar, İ. & Mengeloğlu, F. (2023) The effect of adhesive type and Reinforcement Type on Flexural Deformation of Bending LVL, *Turkish Journal of Forest Science*, 7(1), 110-122

ESER BILGISI /ARTICLE INFO
Araştırma Makalesi / Research Article
Geliş 3 Ocak 2023 / Received 3 January 2023
Düzeltmelerin gelişi 27 Nisan 2023 / Received in revised form 27 April 2023
Kabul 27 Nisan 2023 / Accepted 27 April 2023
Yayımlanma 30 Nisan 2023 / Published online 30 April 2023

ABSTRACT: In this study, the effect of reinforcement type and glue type on the amount of flexural deformation of reinforced bending LVLs was investigated. Within the scope of the study, 2.2mm peeled poplar veneer and 1.5mm peeled alder veneer were used as wood material. Glass fiber and basalt fabric (200g/m²) were used as reinforcement. Alder veneer was used on the lower and upper surfaces, and poplar veneer was used on the middle layers. Reinforcement material was applied to the convex surface of the bending LVL. A total of 7 different combinations of bending LVLs in the form of chair leg-armrest were produced. Flexural test, tensile test and ANSYS analysis were performed on the produced LVLs. According to the test results, it was determined that there was a decrease in flexural deformation with the use of reinforcement. It was determined that the best results were obtained with the use of glass fiber and epoxy. In addition, ANSYS results and real test results were found to be similar.

Keywords: Bending laminated veneer lumber (LVL), ANSYS, epoxy, class fiber, mechanical properties.

TUTKAL TÜRÜ VE GÜÇLENDİRİCİ TÜRÜNÜN BÜKME LVL’NİN EĞİLME DEFORMASYONU ÜZERİNE ETKİSİ

ÖZET: Bu çalışmada güçlendirilmiş bükme LVL’lerin eğilmede deformasyon miktarı üzerine güçlendirici ve tutkal türünün etkisi incelenmiştir. Çalışma kapsamında ahşap malzeme olarak 2,2mm soyma kavak kaplama, 1,5mm soyma kızılağaç kaplama kullanılmıştır. Güçlendirici olarak cam elyafı ve bazalt kumaş (200g/m²) kullanılmıştır. Alt ve üst yüzeyde kızılağaç kaplaması, orta tabakalarda kavak kaplama kullanılmıştır. Güçlendirici malzeme bükme LVL’nin dışbükey yüzeyine uygulanmıştır. Toplam 7 farklı kombinasyonda sandalye ayak-kolçak formunda bükme LVL üretimleri yapılmıştır. Üretilen

LVL'lere eğilme testi, çekme testi ve ANSYS programında eğilme testi yapılmıştır. Test sonuçlarına göre güçlendirici kullanımı ile eğilme deformasyonunda azalma olduğu tespit edilmiştir. En iyi sonucun cam elyafı ve epoksi kullanımı ile sağlandığı belirlenmiştir. Ayrıca ANSYS sonuçları ile gerçek test sonuçlarının benzer olduğu görülmüştür.

Anahtar kelimeler: Bükme tabakalı kaplama kereste, ANSYS, epoksi, cam elyafı, mekanik özellikler.

INTRODUCTION

Solid wood materials use in many areas from past to present. Wood material is used in the construction of elements such as beams and columns in the building sector that requires resistance, as well as in areas such as household goods, toys, hand tools. One of the most important features of solid wood materials is that they can be bent and shaped.

Wood material has limited ability to bend in its natural state. In order to make the wood material bendable, it is necessary to bring it to a certain flexibility. In order to provide this flexibility, the wood material is plasticized. This process also prevents the material from being damaged during the bending process. Wood material can be plasticized using chemicals, microwave, pre-pressure and boiling in water (As and Büyüksarı 2010; Hortaç, 1988).

One of the most commonly used plasticization methods is steaming. It is accepted that the optimum humidity level is 25% in steam bending of wood material (Wright, 2011). Wood is treated with steam, making it softer and easier to bend around a mould. This is achieved by treating the wood material with moisture and heat to the level where it is suitable for bending (Hortaç, 1988). Then the wood is transformed into the desired shape by using molds or guides.

The use of solid wood material as a single piece in large and curved elements is not economically and technically convenient. Because there are defects such as knots, cracks, fiber irregularities in wood material and it is not possible to completely eliminate these defects. The use of solid wood material as a single piece in the production of curved elements is not economical as it increases the waste rate. In addition, since diagonal fiber is formed in the wood material cut according to the curved form, it adversely affects its resistance. Lamination technique is used to eliminate these problems (Karayılmaz et al., 2007).

Lamination is the process of combining at least two wood materials with their fibers parallel to each other (Wagner and Kicklighter, 2000). With this method, bending materials can be produced. Peeling or cutting veneers are brought to the appropriate dimensions and pressed in the mold to take the desired shape after being glued (Hammond and Donnelly, 1966). This method also allows the use of veneers obtained from low quality woods and large-scale wood material production can be realized (Karayılmaz et al. 2007).

With the lamination method, materials with smaller radius can be produced compared to solid wood. The bending radius varies depending on the veneer thickness. The preference of coatings with high bending properties allows the use of thick coatings in lamination. Thus, it provides the opportunity to produce the same thickness material with less layers and glue (As and Büyüksarı, 2010). Furniture, sports equipment, structural elements and many products are made with the lamination method (Wagner and Kicklighter, 2000).

One of the most important lamination products is laminated veneer lumber (LVL). Laminated veneer lumber (LVL), a timber-like product, is an engineered wood material usually obtained by bonding rotary-peeled veneers with their fibers aligned in the same direction. Compared to LVL solid wood, more efficient use of wood, better strength, better dimensional stability and better workability performance can provide. LVL is used as floor beam, main beam, pillar, column and panel in building construction (Nelson, 1997). In addition, some furniture factories produce especially for the purpose of obtaining bent furniture pieces (Dallı, 2005).

Since the veneers that make up LVL are thin, the force required for them to bend is lower than that of solid wood. It is easier to produce in the desired thickness. Mechanical and physical properties can be increased with different glues and reinforcement materials. In addition, some computer programs are used to detect the deformations that will occur at the place of use of such engineered wood materials. Finite element method (ANSYS) is one of them. These computer programs determine how large and costly materials will perform at the place of use. Thus, unnecessary production and costs are avoided by predetermining the most suitable material properties for the place of use.

The aim of this study is to examine the effect of reinforcement type and glue type on the amount of flexural deformation of reinforced bending LVLs in the form of chair leg-armrest. In addition, the bending performances of the produced sample groups were examined in the ANSYS program and compared with the real test results.

MATERIALS AND METHODS

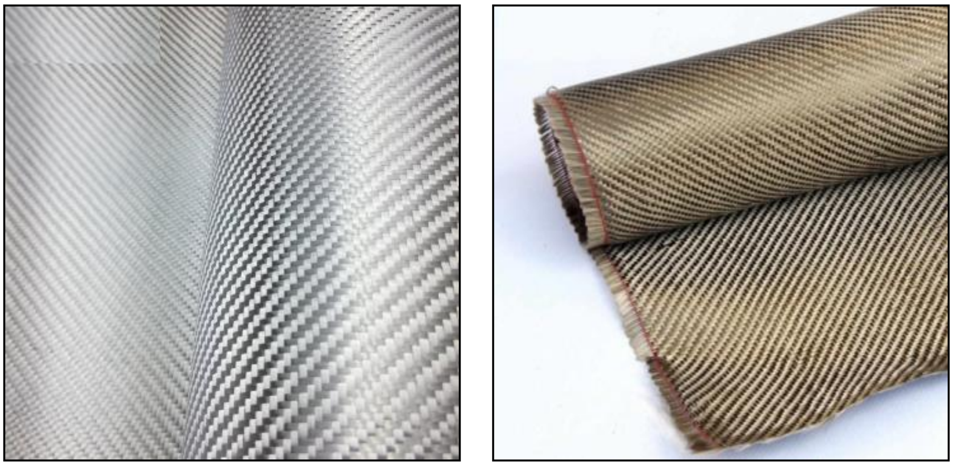
Materials

Bending LVLs have been produced to be used as chair leg-armrest in the furniture industry. The bending LVL produced is given in Figure 1. In the production of LVL, rotary-peeled veneer of 1700 x 65mm, 1.5mm thick alder (*Alnus glutinosa*) and 2.2mm thick poplar (*Populus nigra*) were used at a moisture content of 6-8%. The veneers were purchased from the Petek Plywood factory in Gaziantep. Nine-layer LVLs were produced with outer layers of alder wood and middle layers of poplar veneers. Reinforcement materials were adhered to the outer surface of the bending LVLs. Control groups were produced using urea formaldehyde, phenol formaldehyde and epoxy. Urea formaldehyde glue was used for bonding wooden veneers, epoxy and phenol formaldehyde glue was used for bonding reinforcement materials in the examples using the reinforcement. A total of seven different groups were produced. The production combination is given in Table 4. UF was provided from Adana Kastamonu Integrated Factory (Table 1). Ammonium chloride as a hardener 1.5% was used according to the dry glue amount. For the production of LVL, 200 gr/m^2 of glue was applied to each glue line (ASTM D899, 1994). Phenol formaldehyde (FF) resin Polifen 47 (Polisan, Turkey), epoxy (E) resin LR300/LH300 (Dostkimya, Turkey) were used as adhesives (Table 1). Glass fiber and basalt woven fabrics with a density of 200gr/m^2 were used as reinforcement material. Reinforcement materials were cut in 1700 x 65mm dimensions. 200gr/m^2 glue was used for bonding the reinforcement material (Figure 2).

Table 1. Properties of Urea Formaldehyde, Phenol Formaldehyde and Epoxy

Properties	Urea Formaldehyde Values	Phenol Formaldehyde Values	Epoxy Values
Appearance	Transparent	red brown liquid	Transparent
Solids content (%)	65,21±2	47±1	-
Density (20 ºC) gr/cm^3	1,275	1.2-1.21	1.04
Viscosity (20ºC) cP	236,7	250-500 (cp)	-
Flow time (20ºC, FC4) sec.	74	50-90	-
pH (20ºC)	8,38	10.5-13	-
Free formaldehyde (%)	0,23	max. 1.0	-
Gel time (100ºC) sec.	32	10-20 min	-
Gel time (20-25 °C)	-	-	40min
Gel time (40-45 °C)	-	-	20-30min
Storage time (20ºC) day	30	-	-

Figure 1. LVL in chair leg-armrest form



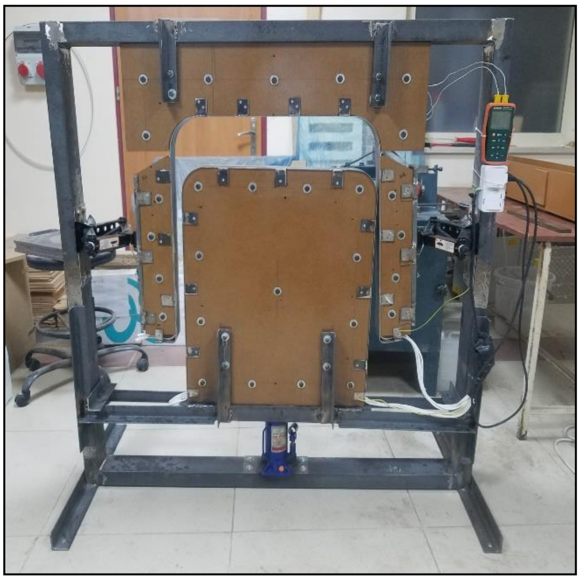
(a) **(b)**

Figure 2. Glass fiber (a) and basalt (b)

Bending Laminated Veneer Lumber Production

Steam cabin and bending press were designed for the production of the bending LVL. Steam cabin and bending press were given in Figure 3. Bending test sample is given in Figure 4. In production, 110 °C temperature, 7 kg/cm2 pressure and 1 mm/min time were applied. The production combination is given in Table 2. In bending LVL production, after the veneers were cut, they were kept in the steaming cabinet for 1 hour and compressed in the form press and kept for 1 day. Then, the veneers were kept until the ambient equilibrium humidity was reached. Bended veneers were glued according to the combinations determined in the production recipe and produced in a bending press. The edges and ends of the samples coming out of the press were cut with a circular saw. Bending LVL test example is given in Figure 1.

(a)



(b)

Figure 3. Steam cabin (a) and bending press (b)

Table 2. Production Combination

Sample Code	Glue Type (LVL)	Glue Type (Reinforcement)	Reinforcement Type	Place of use Reinforcement Materials Convex Surface
ÜF	ÜF	---	---	---
FF	FF	---	---	---
E	E	---	---	---
HFC	ÜF	FF	Glass Fiber	X
HFB	ÜF	FF	Basalt	X
HEC	ÜF	Epoxy	Glass Fiber	X
HEB	ÜF	Epoxy	Basalt	X

The test samples produced were tested in a Zwick Roell 10 kN test device with 20% deformation (bending) within elastic limits (Figure 5). Deformation amounts under 150N load were found. The experimental speed was set at 200 mm/min.

Samples to be used in the tensile strength test were cut from the produced bending LVL. In determining the tensile strength, the principles specified in ASTM D3500-20 standards were followed. According to this standard; the test pieces were prepared as 40.64 cm in fiber direction. The test sample and technical drawing are given in Figure 6. When the test piece was placed, the distance between the pulling jaws was set to 27.24 cm. The test speed was adjusted so that the samples were broken within 3-10 minutes.

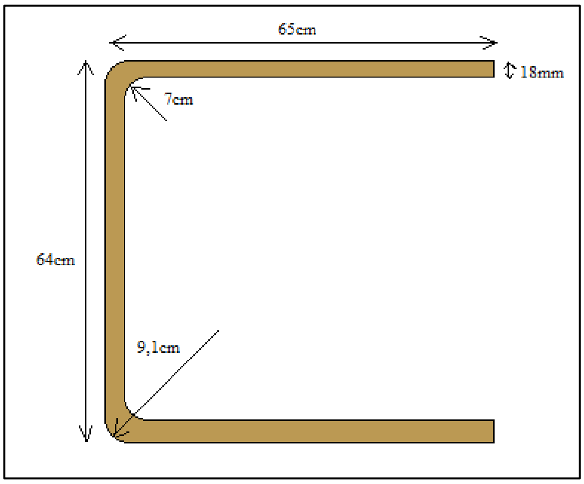
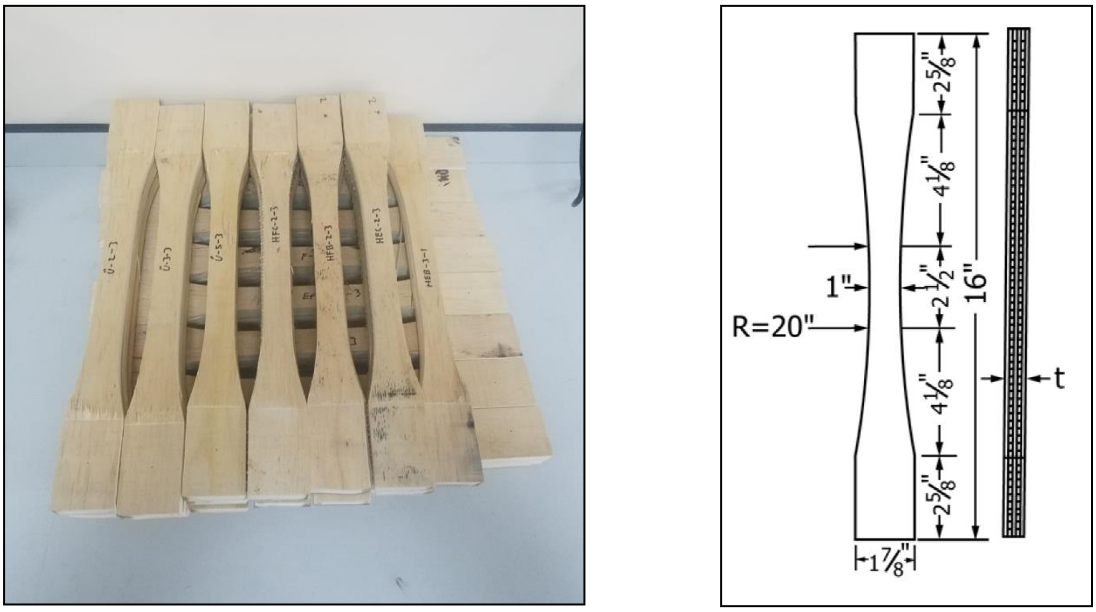


Figure 4. Bending test sample

A tensile strength test was performed to determine the tensile strength value of wood veneers and reinforcement materials. Alder veneer, poplar veneer, fiberglass and basalt were cut in 160 x 20 mm dimensions. The test speed was set to 2mm/min. The test samples produced were tested in a Zwick Roell 10 kN test device.

For ANSYS tests of chair leg-armrest shaped samples, firstly, three-dimensional drawings of the samples were drawn in Autocad program. Young's modulus, Poisson's ratio and density values of the samples were entered into the ANSYS program. “Isotropic elasticity” was chosen because unidirectional force was applied. Poisson's ratio was entered as 0.3. The future of the load and fixed points are entered on the model. Meshing is done. Then the problem was solved and the results were obtained.

Figure 5. Test image of chair leg-armrest samples



(a) **(b)**

Figure 6. The test sample (a) and technical drawing (b)

The obtained data as a result of the tests were analyzed using one-way ANOVA for mechanical properties (p=0,05) from SPSS program. Beside significant differences between groups were determined by Duncan's Multiple range Test (α=0,05).

RESULTS AND DISCUSSION

Simple analysis of variance was performed to determine the effect of adhesive type and reinforcement type on the amount of flexural deformation of the produced bending LVLs, and the results are given in Table 3. The Duncan test results, which were performed to compare the means of variance sources and to determine the homogeneity groups, are given in Table 4.

Table 3. Simple analysis of variance results on the effect of adhesive type and reinforcement type on the amount of flexural deformation of the produced bending LVLs.

Variables	Sum of Squares	Degrees of Freedom	Mean Squares	F	significance level
Between groups	1020,30	6	170,05	45,989	0,000
Within groups	103,53	28	3,70		
Total	1123,84	34			

Table 4. Duncan Test Results for amount of flexural deformation($p \leq 0,05$)

Sample Code	N	Amount of Deformation (mm)
ÜF	5	130,50 **b**
FF	5	125,95 **c**
E	5	133,21 **a**
HFC	5	120,21 **d,e**
HFB	5	121,39 **d**
HEC	5	117,86 **e**
HEB	5	120,18 **d,e**

According to the test results, the lowest deformation amount was found in the HEC (117.86 mm) group, and the highest deformation amount was found in the E group (133.21 mm). With the use of reinforcement, the amount of deformation decreased. The deformation amount of the reinforced samples was lower than the control groups. Although the deformation amount of the samples using the reinforcement gave similar values, glass fiber gave better results than basalt and epoxy gave better results than phenol formaldehyde. The bar graph showing the amount of the average flexural deformation of the samples is given in Figure 7. Compared to the control group, the HFC , HFB , HEC and HEB groups reduced the amount of deformation by 7.88%, 6.98%, 9.69% and 7.91%, respectively, with the reinforcement study. The modulus of elasticity and tensile strength value of the reinforcement materials is higher than veneers. For this reason, it is thought that the amount of flexural deformation of the samples decreases with the use of reinforcement. Tensile strength and modulus of elasticity of veneers and reinforcement materials are given in Table 5.

Bal et al (2015) has produced glass fiber reinforced poplar plywood in different combinations. With the use of glass fiber, an increase in the modulus of elasticity of the plywood was detected, and it was also determined that the use of glass fiber on the outer surface increased the modulus of elasticity more. Moradpour et al (2018) produced a laminated strand lumber (LSL) reinforced with glass fiber using UF and pMDI. According to the test results, the modulus of elasticity of the reinforced LSLs was higher than that of the control groups.

Table 5. Tensile strength and modulus of elasticity of alder veneer, poplar veneer, glass fiber and basalt

Properties	Alder veneer	Poplar veneer	Glass fiber	Basalt
Tensile strength (MPa)	64,97 (8,28)*	75,66 (7,87)	330,60 (12,10)	201,35 (6,60)
Elasticity Modulus (MPa)	3281,73 (380,18)	2761,66 (191,06)	8022,45 (269,29)	4030,79 (173,62)

*Standard deviation

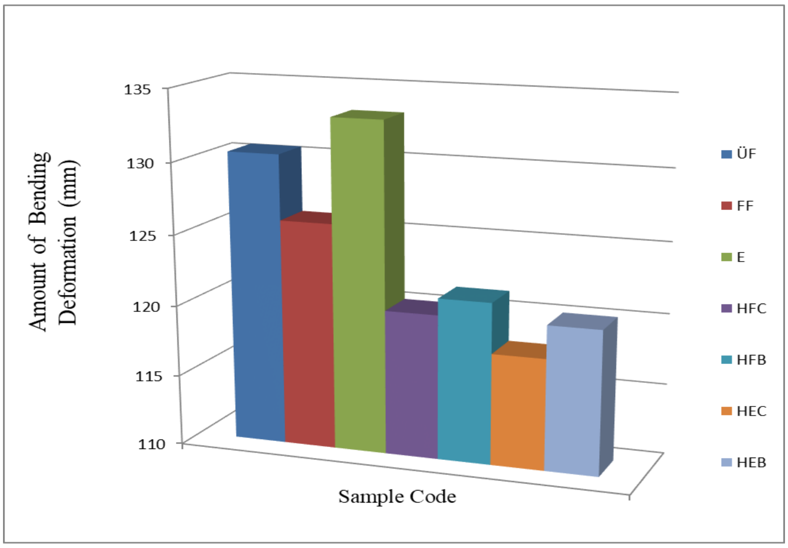


Figure 7. Bar graph showing the amount of flexural deformation of the samples

Tensile strength test was performed on the samples obtained from bending LVLs for use in the ANSYS program. Simple analysis of variance was performed to determine the effect of sample groups on tensile strength and modulus of elasticity and the results are given in Table 6. According to the results of the statistical analysis, it was determined that the sample groups did not have a significant effect on the tensile strength, but had a significant effect on the modulus of elasticity. The Duncan test results, which were conducted to compare the means of variance sources and to determine the homogeneity groups, are given in Table 7.

Table 6. Simple analysis of variance of tensile strength and modulus of elasticity of sample groups

	Variables	Sum of Squares	Degrees of Freedom	Mean Squares	F	significance level
Tensile strength	Between groups	287,86	6	47,98	1,65	0,149
	Within groups	1836,11	63	29,15		
	Total	2123,97	69			
	Variables	**Sum of Squares**	**Degrees of Freedom**	**Mean Squares**	**F**	**significance level**
Modulus of Elasticity	Between groups	13561899	6	2260316	6,72	0,000
	Within groups	21196543	63	336453		
	Total	34758442	69			

Table 7. Duncan test results of tensile strength and modulus of elasticity of sample groups ($p \leq 0.05$)

Sample Code	N	Tensile strength (MPa)
ÜF	10	48,64 **b**
FF	10	51,73 **ab**
E	10	54,48 **a**
HFC	10	52,41 **ab**
HFB	10	53,12 **ab**
HEC	10	55,28 **a**
HEB	10	53,86 **ab**
Sample Code	**N**	**Elasticity Modulus (MPa)**
ÜF	10	11587,40 **c**
FF	10	11898,40 **bc**
E	10	11267,40 **d**
HFC	10	12269,60 **ab**
HFB	10	12403,90 **ab**
HEC	10	12609,40 **a**
HEB	10	12199,10 **ab**

Averages of ANSYS and actual test results are given in Table 8. ANSYS results and actual test results were similar. The lowest deformation amount was found in the HEC group with 118.66 mm, while the highest deformation amount was found in the E group with 132.80 mm. With the strengthening work, the amount of deformation decreased. ANSYS test results are given in Figure 8 and Figure 9.

Table 8. Averages of ANSYS and actual test results

Sample Code	ANSYS Results (mm)	Real Test Results (mm)
ÜF	129,13	130,50
FF	125,75	125,95
E	132,80	133,21
HFC	121,94	120,21
HFB	120,62	121,39
HEC	118,66	117,86
HEB	122,65	120,18

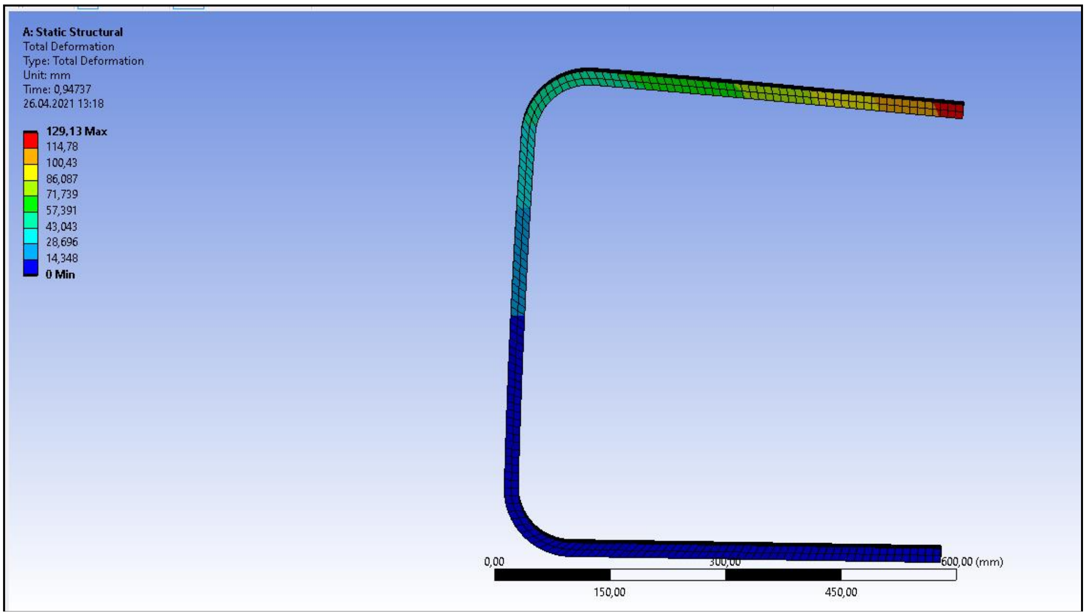


Figure 8. ANSYS test result of UF group

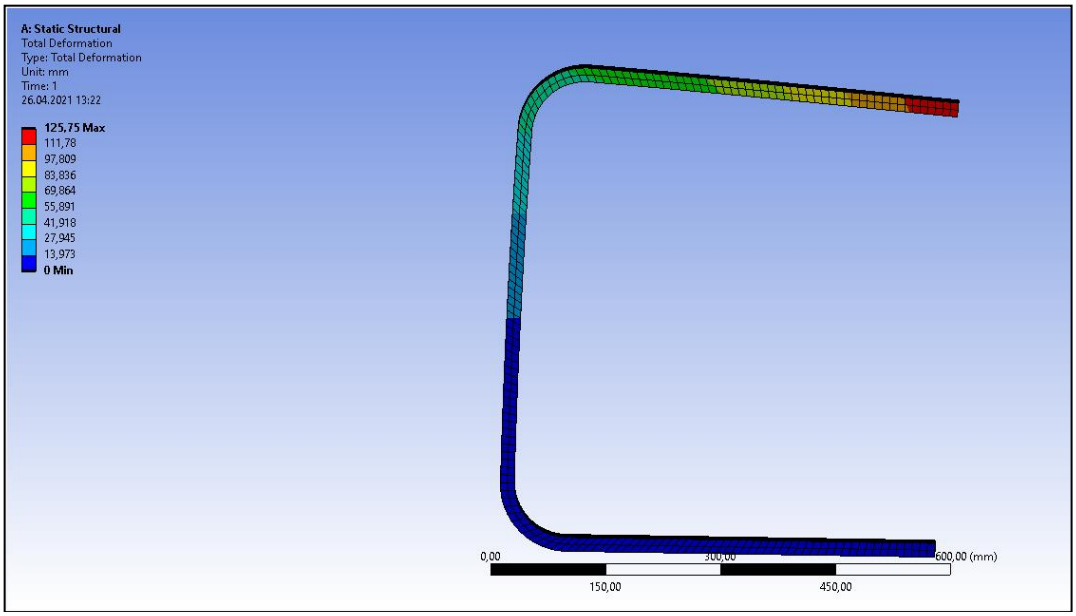


Figure 9. ANSYS test result of FF group

CONCLUSION

As a result of this study;

- When the control groups were compared, the lowest deformation amount was determined in the FF group.
- The test results in the ANSYS simulation program and the actual test results were similar.
- There was a decrease in deformation with the reinforcement study compared to the control groups.
- When the reinforcing type was examined, glass fiber gave better results than basalt.

- The best results were found in the HEC group.
- The highest deformation amount was determined in the E group.

AUTHOR CONTRIBUTIONS

İlkay Atar: Designing the study, collecting data, analyzing data, analysis interpretation of the results, writing the article, **Fatih Mengeloğlu:** Analyzing data, analysis interpretation of the results, writing the article.

FUNDING STATEMENT

This study was supported by the Scientific Research Projects Coordination Unit of Kahramanmaraş Sütçü Imam University with Project no: 2018/2-37D.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

REFERENCES

As, N., Büyüksarı, Ü., (2010). Masif Ağaç Malzemenin Bükülmesi, *Istanbul University Journal of the Faculty of Forestry*, c. 60, sayı 1, s. 29–37.

ASTM D899. (1994). Standard test method for applied weight per unit area of liquid adhesive, *American Society for Testing Materials*, Philadelphia.

ASTM D3500-20. (2020). Standard Test Methods for Wood Structural Panels in Tension, *American Society for Testing Materials*

Bal, B.C., Bektaş, İ., Mengeloğlu, F., Karakuş, K., Demir, H.Ö., (2015). Some Technological Porperties of Poplar Plywood Panels Reinforced with Glass Fiber Fabric, *Construction and Building Materials*, 101; 952-957.

Dallı, G., (2005). Türkiye'de kaplama tabakalı kereste (LVL) üretim imkanlarının araştırılması ve teknolojik özellikleri. Yüksek Lisans Tezi. İstanbul Üniveritesi. *Fen Bilimleri Enstitüsü*. İstanbul. 103s.

Hammond, J. and Donnelly, E. T., (1966). Woodworking Technology, 2. baskı. McKnight & McKnight Publishing Co.

Hortaç, H. K., (1988). Bükme Mobilya Üretim Teknikleri Üzerine Araştırmalar, Yüksek Lisans Tezi, Hacettepe Üniversitesi *Fen Bilimleri Enstitüsü*, Ankara.

Karayılmazlar, S., Çabuk, Y., Atmaca, A., Aşkın, A., (2007). Orman ürünleri endüstrisinde laminasyon tekniği ve önemi. Zonguldak Karaelmas Üniversitesi *Bartın Orman Fakültesi Derigisi*, s. 78–86.

Moradpour, P., Pirayesh, H., Gerami, M., Jouybari, I.R., (2018). Laminated Strand Lumber (LSL) Reinforced by GFRP; Mechanical and Physical Properties, *Construction and Building Materials*, 158;236-242.

Nelson, S., (1997). Structural Composite Lumber. Engineered Wood Products: A Guide for Specifiers, Designers and Users. Edited by Stephen Smulski. PFS Research Foundation, Madison, WI. s. 147-172.

Wagner, W. H., Kicklighter, C. E., (2000). Modern Woodworking. Goodheart- Willcox Publisher.

Wright, R. S., (2011). Vacuum Steam Technology for Rapid Plasticization and Bending of Maple, Virginia Tech.