Gazi Üniversitesi
Fen Bilimleri Dergisi
PART C: TASARIM VE TEKNOLOJİ

Gazi University
Journal of Science
PART C: DESIGN AND TECHNOLOGY

GU J Sci, Part C, 13(3): 1345-1357 (2025)

Performance of L-type Furniture Corner Joints Connected with Dowels Produced in Different Orientations with 3D Printing Technology

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Article Info

Research article
Received: 25/06/2025
Revision: 12/07/2025
Accepted: 21/07/2025

Keywords

Moment Capacity
Stiffness
Diagonal Tension and Compression Tests
Finite Element Method
3D Printing Technology

Makale Bilgisi

Araştırma makalesi
Başvuru: 25/06/2025
Düzeltme: 12/07/2025
Kabul: 21/07/2025

Anahtar Kelimeler

Moment kapasitesi
Elastikiyet
Diyagonal Çekme ve Basınç
Sonlu Elemanlar Yöntemi
3D Yazıcı Teknolojisi

Graphical/Tabular Abstract (Grafik Özet)

This study investigates the moment capacity and stiffness of L-type furniture corner joints assembled with dowels produced in various orientations using 3D printing technology. / Bu çalışmada, 3 boyutlu yazıcı teknolojisi kullanılarak çeşitli yönlerde üretilen kavelalarla birleştirilen L tipi mobilya köşe bağlantılarının moment kapasitesi ve rijitliği araştırılmıştır.

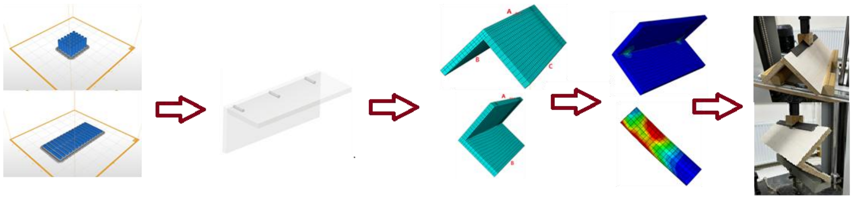

***Figure A**: Summary of the study / **Şekil A:** Çalışma özeti*

Highlights (Önemli noktalar)

- *The dowels utilized in this study were produced by 3D printing in two different orientations (vertical and horizontal) and thus effect of the printing orientation on the performance of the joints was investigated. / Çalışma kapsamında kullanılacak kavelalar, iki farklı yönde (düşey ve yatay) döküm yapılmak suretiyle üretilmiş ve böylece döküm yönünün birleştirmelerin performansı üzerindeki etkisi incelenmiştir.*
- *Dowels and L-type joints have been examined both experimentally and with numerical analyses. / Kavelalar ve L tipi birleştirmeler hem deneysel olarak hem de nümerik analizlerle incelenmiştir.*
- *Dowels are formed on the platform at angles of 0 and 90 degrees using the Layer Plastic Deposition (LPD) method. / Kavelalar, Layer Plastic Deposition (LPD) metodu ile platforma 0 ve 90 derece açı oluşturacak şekilde üretilmiş oluşturulmuştur.*

***Aim (Amaç):** . To determine the effects of dowels produced using different casting directions with LPD technology on the moment capacity and joint elasticity in L-type joints. / LPD teknolojisi kullanılarak farklı döküm yönleriyle üretilen kavelaların, L tipi bağlantılarda moment kapasitesi ve bağlantı elastikiyeti üzerindeki etkilerini belirlemek.*

***Originality (Özgünlük):** The study focuses on the experimental and numerical analyses of the strength of dowles produced using three-dimensional printing technology, which has been frequently used in the production of furniture connections in recent years, based on their printing orientation. / Çalışma, mobilya bağlantı elemanlarının üretiminde son yıllarda sıkça kullanılan üç boyutlu yazıcı teknolojisi ile üretilen bağlantı elemanlarının döküm yönüne göre mukavemetlerinin deneysel ve nümerik olarak analizlerine odaklanmaktadır.*

***Results (Bulgular):** Within the scope of the study; ASA material provided higher results compared to ABS material, horizontal printing orientation provided higher results compared to vertical printing orientation, and the connection type using 3 dowels provided higher results compared to the connection type using 2 dowels. / Çalışma kapsamında; ASA malzeme ABS malzemeye göre, yatay döküm yönü düşey döküm yönüne göre ve 3 kavela kullanılan bağlantı 2 kavela kullanılan bağlantı tipine göre daha yüksek sonuçlar vermiştir.*

***Conclusion (Sonuç):** The stresses that will occur in L-type corner joints can be predicted using FEM analyses, allowing test processes to be shortened and the joint strength to be increased by considering the printing orientation in production with three-dimensional printers. / L tipi köşe birleştirmelerde oluşacak olan gerilmeler FEM analizleri ile tahmin edilerek test süreçleri kısaltılabilir ve üç boyutlu yazıcılar ile yapılacak üretimlerde döküm yönüne dikkat edilerek birleştirme mukavemeti artırılabilir.*

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DOI: 10.29109/gujsc.1727452

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Abstract

This study investigates the moment capacity and stiffness of L-type furniture corner joints assembled with dowels produced in various orientations using 3D printing technology. The dowels utilized in this study were produced by 3D printing in two different orientations (vertical and horizontal) and thus effect of the printing orientation on the performance of the joints was investigated. Two different filament materials, Acrylonitrile Butadiene Styrene (ABS) and Acrylonitrile Styrene Acrylate (ASA), were used to produce the dowels. The produced dowels were used as fasteners in L-type corner joints. In the study, a total of 80 L-type corner joint specimens were prepared with 2 different printing orientation (horizontal and vertical), 2 different number of dowels (2 dowels, 3 dowels) and 10 replications of each specimen, and 40 of them were tested under static diagonal tension and the remaining 40 were tested under static diagonal compression load. In addition, numerical analyses were performed for each group by finite element method (FEM). According to the test results, it was observed that the doweled joints produced from ASA gave higher values than the doweled joints produced from ABS material, and the doweled joints produced in the horizontal orientation gave higher values than the doweled joints produced in the vertical orientation. It was also observed that increasing the number of dowels in the joints from 2 to 3 increased the moment capacity and stiffness of the joints. As a result of the study, the numerical analyses performed by the finite element method were found to be consistent with the actual experimental results and observed deformation characteristics in terms of both forces and stresses.

3B Yazıcı Teknolojisiyle Farklı Döküm Yönünde Üretilen Kavelalarla Bağlanmış L-tipi Mobilya Köşe Birleştirmelerin Performansı

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Öz

Bu çalışmanın amacı, üç boyutlu (3B) yazıcı teknolojisiyle farklı yönlerde üretilen kavelalarla birleştirilmiş, kutu konstrüksiyonlu L-tipi mobilya köşe birleştirmelerinin moment kapasiteleri ve elastikiyetlerinin hem deneysel hem de nümerik olarak araştırılmasıdır. Çalışma kapsamında kullanılacak kavelalar, iki farklı yönde (düşey ve yatay) döküm yapılmak suretiyle üretilmiş ve böylece döküm yönünün birleştirmelerin performansı üzerindeki etkisi incelenmiştir. Kavelaların üretiminde, Akrilonitril Butadiyen Stiren (ABS) ve Akrilonitril Stiren Akrilat (ASA) olmak üzere 2 farklı filament malzemesi tercih edilmiştir. Üretilen kavelalar, L-tipi köşe birleştirmelerde bağlantı elemanı olarak kullanılmıştır. Çalışmada, 2 farklı döküm yönü (yatay ve düşey), 2 farklı kavela sayısı (2 kavelalı, 3 kavelalı) ve her bir örnekten 10 yineleme olmak üzere toplam 80 adet L-tipi köşe birleştirme deney örneği hazırlanmış ve 40'ı statik diyagonal çekme, kalan 40'ı da statik diyagonal basınç yükü altında test edilmiştir. Ayrıca, her bir grup için sonlu elemanlar metodu (FEM) ile nümerik analizler gerçekleştirilmiştir. Deney sonuçlarına göre, ASA malzemeden üretilen kavelalı birleştirmelerin ABS malzemeden üretilen kavelalı birleştirmelere göre; yatay yönde üretilen kavelalı birleştirmelerin de düşey yönde üretilen kavelalı birleştirmelere göre daha yüksek değerler verdiği görülmüştür. Ayrıca birleştirmelerdeki kavela sayısının 2'den 3'e çıkarılmasının birleştirmelerin moment kapasitesini ve elastikiyetini artırdığı görülmüştür. Çalışma sonucunda, Sonlu elemanlar metoduyla gerçekleştirilen nümerik analizler hem kuvvetler hem de gerilmeler açısından gerçek deney sonuçları ve gözlemlenen deformasyon karakteristikleri ile tutarlı bulunmuştur.

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1. INTRODUCTION (GİRİŞ)

Three-dimensional (3D) printing technology is a revolutionary technological advancement in the field of manufacturing. The utilization of three-dimensional printers in the production of prototypes and end products has proven to be a highly efficient process. This method ensures the expeditious production of complex geometric and topographical elements while simultaneously reducing material waste and costs. Furthermore, 3D printing provides a novel manufacturing method for composite materials and modifies the mechanical properties of the printed parts [1–5]. Therefore, 3D printing technology has become widespread in a variety of manufacturing industries for tasks such as modeling, prototyping, preliminary kinematic functional testing, and customized design [6–11]. In the domain of additive manufacturing, particularly in the context of 3D printer technology, a multitude of factors must be taken into consideration to ensure the optimal properties of the end product. These include the material properties of the printing material, the printing speed, and the orientation in which the printer is oriented during the printing process. The furniture industry is also among the industries where productions are made with 3D printer technology. Specifically, 3D printer technology facilitates the production of prototypes for numerous fasteners, enabling the assessment of their mechanical properties. In this context, the production methods employed for the production of the fasteners, as well as the printing orientations utilized by the 3D printer, assume significant importance with respect to the mechanical properties of the resultant components. Recently, an increased level of interest has been observed with regard to ready-to-assemble (RTA) furniture joints [12–15]; the production of fasteners with the 3D printer technology for RTA products has been seen to be both an economical and efficient solution.

L-type diagonal tension and compression tests are one of the most effective tests to determine the mechanical properties, like tension, compression, and bending stresses, of fasteners. The effectiveness of furniture joints such as fasteners or glued dowels as anchors for L-type corner joints has been the subject of numerous studies [12]. For instance, Zhang and Eckelman reported that a study on the diagonal tension and compression tests of L-type joints performed with particleboard (PB) single dowel connections indicated that diagonal tension tests had higher moment capacity than diagonal compression tests [16]. In their study of the stiffness and strength of joints utilized in panel furniture, Smardzewski and Prekrat underscored the significance of trapezoidal joints in attaining optimal stiffness-strength properties. It was highlighted that wooden dowels play a critical role in enhancing the strength of such joints [17].

In a recent study, Kasal et al. investigated the mechanical properties of auxetic dowels produced using 3D printer technology. The dowels were put through diagonal tension and compression tests as part of the experimental setup, and the finite element method (FEM) was used to model L-type joints. As a conclusion, further improvements are required before auxetic dowels may be used as a substitute for traditional dowels [12]. In a particular study that examined the application of FEM analysis, FEM analyses proved to be a viable solution to assess the occurred stresses in furniture. A wooden chair was analyzed using FEM by Gustafsson in research. FEM analyses results were compared to the results of the actual test. In summary, it has been indicated that the analysis of chair frames can be conducted through the utilization of computer-aided structural analysis methodologies [18]. A comparison and investigation of the difficulties associated with the utilization of the finite element method (FEM) in the context of wood materials has been conducted through the implementation of performance tests utilizing finite element software [19]. When the literature is examined, it is seen that there are a limited number of studies investigating the effects of printing orientation on strength in three-dimensional printers. Accordingly, in this study, the effects of the printing orientation on the strength of the materials in three-dimensional printers, especially in the production of furniture fasteners, were investigated. The utilization of 3D printing technology has seen a marked increase in the production of fasteners and prototypes within the furniture industry. While a multitude of 3D printing technologies exist, one of the most prevalent in the realm of prototype production is the Layer Plastic Deposition (LPD) method. This method has been successful in the production of various fasteners and dowels. The strength of the produced dowels is related to the casting method and raster orientations. In the study, test specimens were produced using two different raster orientations: the initial orientation of the object is at a 90° angle with respect to the vertical axis, and the horizontal axis is at 0°. The study investigated the strength of dowels produced with LPD technology in 0° and 90° raster orientations [20,21] under diagonal tensile and compression tests in L-type joints. In this study, it was aimed to determine the effects of dowels produced using different casting directions with

LPD technology on the moment capacity and joint elasticity in L-type joints.

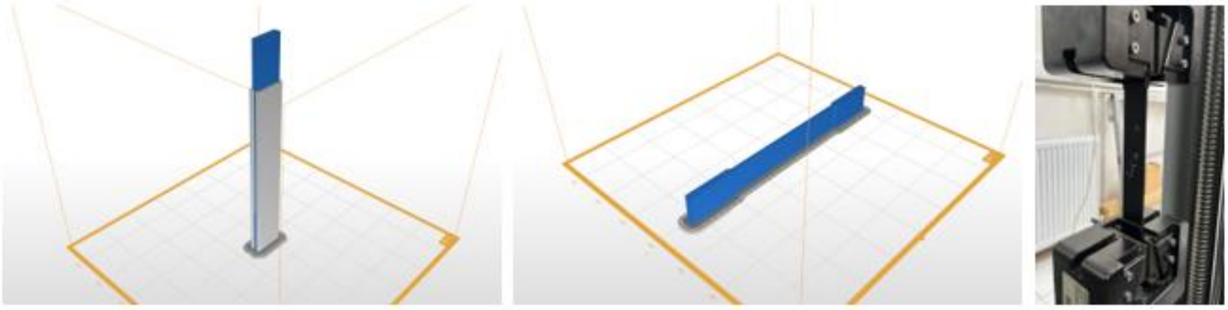
2. MATERIALS AND METHODS (MATERYAL VE METOD)

2.1. Test Materials (Test Malzemeleri)

Within the scope of the study, the L-type corner joint specimens were made from melamine-coated particleboard, and the dowels were made from ABS and ASA filaments. ABS filaments are suitable for 3D printers with a nozzle temperature of 220-260 °C, no special hot-end required, 80 °C platform temperature, 0,1 mm detailed printing. ASA filaments are suitable for 3D printers with a nozzle temperature of 250-280 °C, no special hot-end, 90 °C platform temperature, 0,1 mm detailed printing diameter [22]. In this study, ABS filament was printed with a layer resolution of 0.1 mm at a nozzle temperature of 240 °C and a platform temperature of 80 °C, following the manufacturer's recommendations. All specimens were produced with nozzle which diameter was 0.4 mm. Since all test samples were produced with 100% infill rate, the infill type was selected as solid in Zortrax M300plus. Within the scope of the study, the densities of ABS and ASA filaments and their tensile strength and modulus of elasticity (MOE) values were determined according to the principles specified in the ASTM D3039/D3039M-17 [23] standard. The specimens used in these tests were produced with a three-dimensional printer.

2.2. Tensile Specimens (Çekme Deneyi Örnekleri)

Tensile specimens were prepared using a Zortrax M300plus printer (Poland) with 0.1 mm dimensional tolerance. 10 specimens were prepared in total. Specimens were produced in both vertical (Figure 1a) and horizontal (Figure 1b) orientations. Tensile strength and modulus of elasticity of the specimens were calculated separately for each printing orientation. Tensile tests were performed on a universal testing machine with a 50 kN capacity (Figure 1c).



a. b. c.

Figure 1. a. Tensile specimens in vertical orientation b. tensile specimen in horizontal orientation, c. tensile test (a. Dikey yönde çekme numuneleri b. yatay yönde çekme numuneleri, c. çekme testi)

The data obtained from the tensile tests were used to define the materials for FEM analysis of L-type corner joints. Since each material has different modulus of elasticity and stress values in different printing orientations, the properties of ABS and ASA filaments were defined separately in the FEM program for horizontal and vertical production. In this case, instead of 2 material definitions, 4 material definitions were used to perform the FEM analysis.

2.3. Preparation and Diagonal Tests of L-type Corner Joints (L tipi deney örneklerini hazırlanışı ve diyagonal testleri)

Dowels produced as part of the study were categorized into two distinct groups based on their orientation, namely, vertical (Figure 2a) and horizontal (Figure 2b), in a manner consistent with the tensile specimens. All dowels produced within the scope of the study had the same dimensions; the diameter of the dowels was 10 mm and the length was 40 mm.

a. b.

Figure 2. Dowels produced a. in vertical orientation, b. in horizontal orientation (Üretilen kavelalar a. düşey yön, b. yatay yön)

L-type corner joints tested within the scope of the study, two different groups were applied as joints prepared with 2 dowels (Figure 3a) and joints prepared with 3 dowels (Figure 3b). In L-type corner joints, holes were drilled so that the dowel axis was 37 mm inside from the front edge of the specimens and the second dowel was 52 mm inside from the back edge. For L-type joints produced with two dowels, the distance between the dowel axes is 288 mm, and for L-type joints produced with three dowels, the distance between the dowel axes is 144 mm.

a. b.

Figure 3. Joints prepared with a) 2 dowels, b) 3 dowel joints. (Birleştirmeler a. 2 kavelalı, b. 3 kavelalı)

During usage, corner joints in panel furniture are commonly exposed to the tensile forces, which try to open the corner joint, and compressive forces, which try to close the joint angle. Under tension and compression, moments occurred at the corner of panel furniture or L-type joints. These two significant loading models were used for this study's test procedure in order to assess the stiffness and strength of L-type corner joints with dowels produced in a 3D printer. Diagonal tension (Figure 4a) and compression (Figure 4b) tests were performed with a 50 kN capacity testing machine.

a. b.

Figure 4. a. Diagonal tension test, b. Diagonal compression test (a. Diyagonal çekme testi, b. Diyagonal basınç testi)

The maximum forces were obtained during the tension and compression experiments, and the displacement and deformation of L-type corner joints was determined. Tests were performed on 80 L-type specimens, 40 of which were tested under diagonal tension and the remaining 40 were tested under diagonal compression loading. The moment capacities (Nm) of the joints under tension or compression were first determined. The moment was divided by the corresponding change in the joint angle between the arms of the connection to determine the stiffness (Nm/rad) values [12]. The experimental design of the study was given in Table 1.

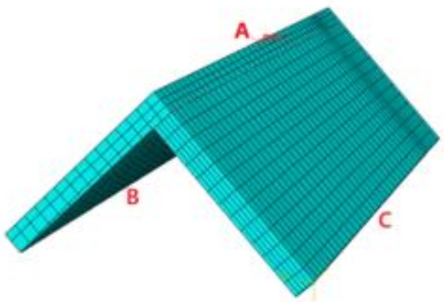
Table 1. Experimental design of the study (Çalışmanın deneme deseni)

Material	Orientation	Number of Dowel	Diagonal Tension	Diagonal Compression
ABS	Vertical	2 Dowels	5	5
		3 Dowels	5	5
	Horizontal	2 Dowels	5	5
		3 Dowels	5	5
ASA	Vertical	2 Dowels	5	5
		3 Dowels	5	5
	Horizontal	2 Dowels	5	5
		3 Dowels	5	5
Total			40	40

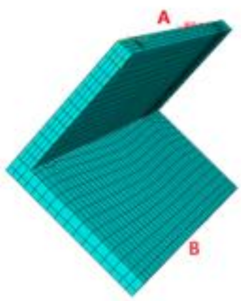
2.4. Numerical Analyses of L-type Corner Joints

(L tipi deney örneklerini hazırlanışı ve diyagonal testleri)

By simulating the displacement of fasteners using the finite element method, the damage mechanism of dowels was examined. ABS and ASA materials are defined with a Poisson's ratio of 0.3 for the dowels. Materials are defined separately for horizontal and vertical directions. In this context, since horizontal and vertical directions are defined for ABS and ASA materials, material identification is performed as if four different materials were used. MOE values are defined as 1213 MPa for ABS vertical, 1385 MPa for ABS horizontal, 988 MPa for ASA vertical and 1250 MPa for ASA horizontal. Joints were constructed with the dimensions of the tested specimens, as shown in Figure 5, using the commercial software ABAQUS/Explicit v6.14 (Dassault Systemes Simulia Corp., Waltham, Ma, USA). L-type corner joints were modeled in a virtual environment in real dimensions and transferred to the finite element program. Boundary conditions were determined with the help of some simplifications and assumptions for the analysis of diagonal tension and compression tests (Figure 5a, Figure 5b). Numerical analyses were performed using an average of 10000 nodes and 8000 elements in tension tests and 7400 nodes and 5200 elements in compression test. In general, the hourglass control element was used, which is an 8-node linear brick with reduced integration.



a.



b.

Figure 5. a. Diagonal tension test, b. Diagonal compression test in FEM analyses (FEM analizlerinde a. diyagonal çekme, b. diyagonal basınç testi)

The vertical deformations (mm) obtained from the actual tests were applied from the point A shown in Figure 5 for both the tension and compression tests. The supports were applied as roller support at points B and C in the diagonal tensile tests shown in Figure 4a and as pin support at point B in the diagonal compression tests shown in Figure 5b. The analysis results included a comparison between the actual test results and the maximum reaction force at point A as well as the stresses at the moment of this force.

3. RESULTS (BULGULAR)

3.1. Experimental Results (Deney Sonuçları)

Results obtained from the moisture content, oven-dry density, and air-dry density tests performed for the particleboard used in the preparation of the test specimens are given in Table 2. Densities of ABS and ASA materials used in the production of dowels were determined as 1,10 g/cm3 and 1,07 g/cm3, respectively.

Table 2. Moisture content, oven dry density and air-dry density of particleboard used in study (Çalışmada kullanılan yonga levha malzeme için rutubet miktarı, tam kuru yoğunluk ve havakurusu yoğunluk)

Wood Material	Moisture (%)	Oven Dry Density (gr/cm^3)	Air Dry Density (gr/cm^3)	Bending Stress (MPa)	MOE (MPa)
Particleboard	6,98	0,62	0,65	16	3268

MOE: Modulus of Elasticity

Stress of the tensile test specimens prepared vertical orientation ABS material was found 10,46 MPa and modulus of elasticity (MOE) was found 1213 MPa; for the horizontal orientation printed ABS material, the tensile stress was found 36,41 MPa and the MOE was found 1275 MPa. Also, for the vertical orientation printed ASA material, the tensile stress was found 13,15 MPa and the MOE was found 988 MPa; for the horizontal orientation printed ABS material, the tensile stress was found 37,97 MPa and the MOE was found 1250 MPa. MOE values were calculated for each group using the mean stress and strain values obtained from the tests. The obtained MOE values were used in material definitions in FEM analyses.

After the tensile tests of materials, diagonal tension and compression tests were performed for L-type joints. Moment carrying capacity and stiffness were presented in diagonal tension and diagonal compression tests (Table 3).

Table 3. Moment and stiffness values of L-type corner joints (L-tipi birleştirmelerde moment ve elastikiyet değerleri)

	Material	Orientation	Number of Dowel	Moment (Nm)	Stiffness (Nm/Rad)
Diagonal Tension Test	ABS	Vertical	2 Dowels	12,27 (5,67)	492,41 (9,61)
			3 Dowels	17,94 (7,79)	724,02 (8,72)
		Horizontal	2 Dowels	16,82 (7,49)	407,80 (5,71)
			3 Dowels	21,66 (2,91)	604,38 (8,53)
	ASA	Vertical	2 Dowels	16,55 (2,25)	479,17 (6,13)
			3 Dowels	23,61 (3,82)	659,83 (3,85)
		Horizontal	2 Dowels	17,20 (6,16)	524,90 (6,21)
			3 Dowels	25,56 (4,87)	618,14 (7,72)
Diagonal Compression Test	ABS	Vertical	2 Dowels	4,83 (7,69)	74.53 (8,93)
			3 Dowels	8,55 (4,34)	117,45 (8,60)
		Horizontal	2 Dowels	6,51 (9,04)	68,45 (11,99)
			3 Dowels	7.06 (10,53)	91,13 (8,54)
	ASA	Vertical	2 Dowels	6,51 (9,04)	70,52 (10,70)
			3 Dowels	11,15 (5,27)	109,96 (1,95)
		Horizontal	2 Dowels	5,95 (7,65)	66,02 (7,67)
			3 Dowels	12,08 (8,43)	125,81 (8,67)

*Values in parenthesis are Coefficient of Variation

In order to investigate the impact of filament type as a material and printing orientation on the mean stiffness and moment capacity under diagonal tension and diagonal compression loading, multiway analyses of variances (MANOVA) were implemented for both stiffness and the moment capacity data of L-type corner joints. MANOVA results of L-type corner joint for diagonal tension and diagonal compression tests were given in Table 4.

According to the results of the MANOVA, for both loading types, the impact of the material factor as an independent variable on the stiffness and moment capacity was statistically significant at the 5% level.

Therefore, the mean differences in moment capacity and stiffness values between the L-type joints assessed were calculated using the least significant difference (LSD) comparisons approach at the 5% significance level. Triple interactions were statistically insignificant in diagonal tensile tests, while LSD comparisons were significant for main variables.

Table 4. Analysis of variance for L-type joints diagonal tension and compression tests (L-tipi birleştirmelerde diyagonal çekme ve basınç testleri için varyans analizi sonuçları)

		Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value	P-Value
Diagonal Tension Tests	Moment (Nm)	Material (M)	1	126,404	126,404	100,47	0,000
		Orientation (O)	1	73,918	73,918	58,75	0,000
		Dowel Numb. (D)	1	420,325	420,325	334,08	0,000
		MxO	1	20,093	15,168	15,97	0,000
		MxD	1	15,168	0,135	12,06	0,002
		OxD	1	0,135	2,856	0,11	0,745
		MxOxD	1	2,856	1,258	2,27	0,142
		Error	32	40,261			
		Total	39	699,159			
	Stiffness (Nm/Rad)	Material (M)	1	1784	1784	0,80	0,378
		Orientation (O)	1	25052	25052	11,23	0,002
		Dowel Numb. (D)	1	308062	308062	138,14	0,000
		MxO	1	27116	27116	12,16	0,001
		MxD	1	14878	14878	6,67	0,015
		OxD	1	9372	9372	4,20	0,049
		MxOxD	1	1716	1716	0,77	0,387
		Error	32	71364	2230		
		Total	39	459343			
Diagonal Compression Tests	Moment (Nm)	Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value	P-Value
		Material (M)	1	47,713	47,713	98,18	0,000
		Orientation (O)	1	0,194	0,194	0,40	0,532
		Dowel Numb. (D)	1	141,712	141,712	291,60	0,000
		MxO	1	0,022	0,022	0,04	0,834
		MxD	1	26,459	26,459	54,44	0,000
		OxD	1	1,750	1,750	3,60	0,067
		MxOxD	1	13,499	13,499	27,78	0,000
		Error	32	15,551	0,486		
		Total	39	246,900			
	Stiffness (Nm/Rad)	Material (M)	1	269,0	269,0	3,58	0,067
		Orientation (O)	1	276,6	276,6	3,68	0,064
		Dowel Numb. (D)	1	16979,3	16979,3	266,17	0,000
		MxO	1	1196,4	1196,4	15,94	0,000
		MxD	1	706,4	70,.4	9,41	0,004
		OxD	1	0,0	0,0	0,00	0,992
		MxOxD	1	1029,4	1029,4	13,71	0,001
		Error	32	2402,3	75,1		
		Total	39	22859,6			

The triple interaction showed considerable results in studies of diagonal compression. Thus, the comparison findings of the triple interaction for the diagonal compression tests and the main factor comparisons for the diagonal tensile tests are given in Table 5.

Table 5. Comparison results for main factors of diagonal tension tests (Diyagonal çekme testi için ana faktörlerin karşılaştırmalı sonuçları)

Diagonal Tension Tests					
		Moment		Stiffness	
		X (Nm)	HG	X (Nm/Rad)	HG
Material	ABS	17,17	B	-	-
	ASA	20,73	A	-	-
Orientation	Vertical	17,59	B	588,857	A
	Horizontal	20,31	A	538.805	B
Dowel Number	2 Dowels	15,71	B	476,07	B
	3 Dowels	22,19	A	651,59	A

*X: Mean Values, HG: Homogeneity Group

Table 5 shows that the moment capacity of L-type corner joints made with ASA was almost 21% greater when the material's major variables are examined in the diagonal tension test. Stiffness values of this factor were not statistically significant. It was shown that dowels made in a horizontal orientation had 15% greater moment capacity values when the printing orientation was examined as a main factor. Analysis of the stiffness values for the same factor revealed that dowels made vertical orientation values that were 9% higher. The moment values of L-type corner joints made with three dowels are 37% higher than those made with two dowels, according to an analysis of the primary determinant of the number of dowels. When the elasticity values were analyzed for the same factor, it was determined that the joints produced with 3 dowels gave 37% higher values. In diagonal compression tests, triple interaction results were analyzed, and comparisons are given in Table 6.

Table 6. Comparison results for interaction of diagonal compression tests (Diyagonal basınç testi için üçlü etkileşim karşılaştırmalı sonuçları)

Diagonal Compression Tests						
Material	Orientation	Dowel Number	Moment		Stiffness	
			X (Nm)	HG	X (Nm/Rad)	HG
ABS	Vertical	2 Dowels	4,83	F	74,53	D
		3 Dowels	8,55	C	117,45	AB
	Horizontal	2 Dowels	6,51	DE	68,45	D
		3 Dowels	7,06	D	91,13	C
ASA	Vertical	2 Dowels	6,51	DE	70,52	D
		3 Dowels	11,12	B	109,96	B
	Horizontal	2 Dowels	5,95	E	66,02	D
		3 Dowels	12,08	A	125,81	A

Table 6 shows that the specimens made from ASA material in the horizontal orientation and with three dowels had the maximum moment and elasticity values for the L-type specimens in the diagonal compression test.

3.2. Failure Modes (Deformasyon Karakteristikleri)

When the failure modes were examined in diagonal tension tests, it was observed that the dowels were broken in the test specimens prepared with dowels produced in vertical orientation (Figure 6a), while in the test specimens prepared with dowels produced in horizontal orientation, the dowel broke the particleboard and came out of the dowel hole (Figure 6b).

a. b.

Figure 6. Failure modes in diagonal tension test a) dowel produced in vertical orientation, b) dowel produced in horizontal orientation (Diyagonal çekme testi için deformasyon karakteristikleri a. düşey yönde üretilen kavela, b. yatay yönde üretilen kavela)

When the failure modes of the compression tests were examined, as in the tensile tests, the dowels were broken in the test specimens prepared with dowels produced in the vertical orientation (Figure 7a), while the particleboard was deformed in the test specimens prepared with dowels produced in the horizontal orientation (Figure 7b).

. a. b.

Figure 7. Failure modes in diagonal compression test a) dowel produced in vertical orientation, b) dowel produced in horizontal orientation (Diyagonal basınç testi için deformasyon karakteristikleri a. düşey yönde üretilen kavela, b. yatay yönde üretilen kavela)

3.3. FEM Results (FEM Sonuçları)

Maximum stress and reaction forces were analyzed in FEM analyses, and maximum reaction forces were compared with actual test results. The deformation characteristics of FEM were also compared with the deformation characteristics obtained from actual tests (Table 7).

Table 7. Comparison results for actual tests and FEM (Deney sonuçları ve FEM analizi karşılaştırması)

Material	Orientation	Dowel Number	Diagonal Tension			Diagonal Compression		
			Actual Tests (N)	FEM (N)	Differences (%)	Actual Tests (N)	FEM (N)	Differences (%)
ABS	Vertical	2 Dowels	258,98	301	16,22	51,01	53	3,90
		3 Dowels	378,67	315	-16,81	90,25	85	-5,82
	Horizontal	2 Dowels	355,12	430	21,09	68,67	77	12,13
		3 Dowels	457,15	502	9,81	74,56	99	32,79
ASA	Vertical	2 Dowels	349,24	326	-6,65	68,67	61	-11,17
		3 Dowels	498,35	331	-33,58	117,72	98	-16,75
	Horizontal	2 Dowels	362,97	375	3,31	62,78	67	6,72
		3 Dowels	539,55	499	-7,52	127,53	115	-9,83

When actual tests and FEM analyses were compared for diagonal tension tests, the group that used three dowels made with ASA material in the vertical orientation was projected to differ by 33%. The results of the FEM analysis seem to be satisfactory other than that. When actual testing and FEM analyses were compared for diagonal compression tests, the group that used three dowels made with ASA material in the vertical orientation was projected to differ by 32%. FEM analyses can be improved by applying denser meshes and different boundary conditions. Furthermore, FEM analyses were conducted using data from experimental tests to define plasticity. Nonlinear behavior can be defined with more accuracy. These definitions can help ensure more accurate and realistic solutions. The results of the FEM analysis seem to be satisfactory other than that. In addition, the failure modes in FEM are consistent with the failure modes obtained from real tests (Figure 8, Figure 9).

a. b.

Figure 8. Failure modes in diagonal tension test for FEM a) particleboard failure mode b) dowel failure mode (Diyagonal çekme testi için deformasyon karakteristikleri a. yonga levha deformasyonu, b. kavela deformasyonu)

a. b.

Figure 9. Failure modes in diagonal compression test for FEM a) particleboard failure mode b) dowel failure mode (Diyagonal basınç testi için deformasyon karakteristikleri a. yonga levha deformasyonu, b. kavela deformasyonu)

Examining the deformation characteristics revealed that the dowels and the L-type corner joint test specimens both had deformations that were comparable to those observed in the actual test. The stresses obtained from FEM analyses were analyzed for both the dowels and the particleboard. Stress values obtained from FEM analysis are given in Table 8.

Table 8. Maximum Principal Stresses obtained from FEM analyses (FEM analizlerinden elde edilen en yüksek gerilme değerleri)

Material	Orientation	Dowel Number	Diagonal Tension		Diagonal Compression	
			PB Max. Principal Stress (MPa)	Dowel Max. Principal Stress (MPa)	PB Stress Max. Principal (MPa)	Dowel Stress Max. Principal (MPa)
ABS	Vertical	2 Dowels	19,52	11,37	4,23	11,37
		3 Dowels	18,72	11,46	5,18	11,58
	Horizontal	2 Dowels	21,32	36,71	7,70	26,42
		3 Dowels	19,13	34,36	4,96	18,47
ASA	Vertical	2 Dowels	15,13	12,01	3,29	13,21
		3 Dowels	18,90	12,87	5,69	13,24
	Horizontal	2 Dowels	20,98	28,91	7,24	22,58
		3 Dowels	22,01	28,86	6,21	23,89

The stress values in the L-type test specimens made with dowels manufactured in vertical orientation were higher than the stresses found in the tensile tests when the stress levels were analyzed. For instance, it was found that the average stress in dowels with vertical orientation from ABS tensile test specimens was 10,46 MPa. Examining the same group's stresses in FEM studies reveals that the dowel stresses are higher than 11 MPa. The occurrence of dowel fracture deformations, as shown in the deformation characteristics, corresponds with this. L-type test specimens constructed using ASA-made dowels with vertical orientation are likewise subject to the strains described above. In vertical tensile tests, the highest stress generated by ASA material was found to be 13,14 MPa. According to FEM analysis, the stresses in the same group were 13,21 MPa. This aligns with the properties of deformation as well.

When the stress values of the dowels produced in the horizontal orientation are examined, it is determined that the stresses in the dowels in FEM analyzes are much lower than the stresses obtained from tensile tests. This aligns with the deformation properties seen in actual tests. Tensile test specimens made with ABS material in a horizontal orientation have an average stress value of 36,04 MPa, whereas those made of ASA material have an average stress value of 37,98 MPa. However, it is observed that the particleboards are deformed before the dowel stresses produced in the horizontal orientation reach the maximum, and their stresses surpass the maximum stress value when the test specimens prepared with dowels produced in the horizontal orientation in L-type diagonal tensile and compression tests are examined.

4. CONCLUSION (SONUÇLAR)

Recently, 3D printer technology has gained a lot of attention and is widely used, particularly for prototyping. The furniture industry has begun to use 3D printer technology extensively, and production technology, material, and printing orientation are important in the production process of 3D printing.

Within the scope of the study, 3D printer technology was used to create dowel in both horizontal and vertical orientations. The prepared dowel samples were utilized for diagonal tensile and compression tests in L-type corner joints. Both actual tests and FEM analyses of L-type joints were performed, and the results were compared.

When the L-type diagonal tension tests were examined, it was observed that the dowels made of ASA material gave better results than the dowels made of ABS material. When the 3D printer printing orientation is examined, it is seen that the dowels produced in the horizontal orientation gave higher values than the dowels produced in the vertical orientation. In addition, when the joints produced with 3 dowels and the joints produced with 2 dowels were examined, it was determined that the joints using 3 dowels gave higher values. Out of the three dependent factors that were analyzed, the number of dowels had the biggest impact, followed by the orientation of production, and the material dependent variable had the least impact. This may be due to the similar properties of ASA and ABS materials. Therefore, the effect of the material factor can be examined by performing L-type diagonal tests with more materials.

Forces and stresses were found to be rather similar when the finite element analyses were examined. In two groups, however, the comparison percentages were high. This can be because wood composite materials are hard to define in FEM systems. However, by varying the test and constraint circumstances, the derived values can be improved, and FEM analysis can produce more accurate predictions. Therefore, producing fasteners using 3D printing in alignment with the load direction can result in stronger connections. Additionally, production and testing procedures can be improved by using FEM analysis to calculate the stresses that will occur in these fasteners and joints.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Tolga KUŞKUN*:** He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

REFERENCES (KAYNAKLAR)

[1] Ning F, Cong W, Qiu J, Wei J, Wang S. Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. Compos Part B Eng 2015;80:369–78. https://doi.org/https://doi.org/10.1016/j.compositesb.2015.06.013.

[2] Masood SH, Song WQ. Development of new metal/polymer materials for rapid tooling using Fused deposition modelling. Mater Des 2004;25:587–94. https://doi.org/https://doi.org/10.1016/j.matdes.2004.02.009.

[3] Farina I, Fabbrocino F, Carpentieri G, Modano M, Amendola A, Goodall R, et al. On the reinforcement of cement mortars through 3D printed polymeric and metallic fibers. Compos Part B Eng 2016;90:76–85. https://doi.org/https://doi.org/10.1016/j.compositesb.2015.12.006.

[4] Kuo C-C, Liu L-C, Teng W-F, Chang H-Y, Chien F-M, Liao S-J, et al. Preparation of starch/acrylonitrile-butadiene-styrene copolymers (ABS) biomass alloys and their feasible evaluation for 3D printing applications. Compos Part B Eng 2016;86:36–9. https://doi.org/https://doi.org/10.1016/j.compositesb.2015.10.005.

[5] Zou R, Xia Y, Liu S, Hu P, Hou W, Hu Q, et al. Isotropic and anisotropic elasticity and yielding of 3D printed material. Compos Part B Eng 2016;99:506–13. https://doi.org/10.1016/j.compositesb.2016.06.009.

[6] Rahim SL, Maidin S. Feasibility Study of Additive Manufacturing Technology Implementation in Malaysian Automotive Industry Using Analytic Hierarchy Process. Adv Mater Res 2014;903:450–4. https://doi.org/10.4028/www.scientific.net/AMR.903.450.

[7] Richter C, Lipson H. Untethered Hovering Flapping Flight of a 3D-Printed Mechanical Insect. Artif Life 2011;17:73–86. https://doi.org/10.1162/artl_a_00020.

[8] Gebler M, Schoot Uiterkamp AJM, Visser C. A global sustainability perspective on 3D printing technologies. Energy Policy 2014;74:158–67. https://doi.org/https://doi.org/10.1016/j.enpol.2014.08.033.

[9] Lee J-Y, Tan WS, An J, Chua CK, Tang CY, Fane AG, et al. The potential to enhance membrane module design with 3D printing technology. J Memb Sci 2016;499:480–90. https://doi.org/https://doi.org/10.1016/j.memsci.2015.11.008.

[10] Mironov V, Boland T, Trusk T, Forgacs G, Markwald RR. Organ printing: computer-aided jet-based 3D tissue engineering. Trends Biotechnol 2003;21:157–61. https://doi.org/https://doi.org/10.1016/S0167-7799(03)00033-7.

[11] Seitz H, Rieder W, Irsen S, Leukers B, Tille C. Three-dimensional printing of porous ceramic scaffolds for bone tissue engineering. J Biomed Mater Res - Part B Appl Biomater 2005;74:782–8. https://doi.org/10.1002/jbm.b.30291.

[12] Kasal A, Smardzewski J, Kuşkun T, Güray E. Analyses of L-Type Corner Joints Connected with Auxetic Dowels for Case Furniture. Materials (Basel) 2023;16. https://doi.org/10.3390/ma16134547.

[13] Pizzi A, Despres A, Mansouri HR, Leban J-M, Rigolet S. Wood joints by through-dowel rotation welding: microstructure, 13C-NMR and water resistance. J Adhes Sci Technol 2006;20:427–36. https://doi.org/10.1163/156856106777144327.

[14] Segovia C, Pizzi A. Performance of Dowel-Welded T-Joints for Wood Furniture. J Adhes Sci Technol 2009;23:2073–84. https://doi.org/10.1163/016942409X12526743387926.

[15] Stamm B, Natterer J, Navi P. Joining of wood layers by friction welding. J Adhes Sci Technol 2005;19:1129–39. https://doi.org/10.1163/156856105774429046.

[16] Zhang J-L, Eckelman CA. The bending moment resistance of single-dowel corner joints in case construction. For Prod J 1993;43:19.

[17] Smardzewski J, Prekrat S. Stress Distribution in Disconnected Furniture Joints. Electron J Polish Agric Univ 2002;5:1–7.

[18] Gustafsson S-I. Optimising ash wood chairs. Wood Sci Technol 1997;31:291–301. https://doi.org/10.1007/BF00702616.

[19] Koç KH, Kizilkaya K, Erdinler ES, Korkut DS. The use of finite element method in the furniture industry. African J Bus Manag 2011;5:855–65. https://doi.org/10.5897/AJBM10.551.

[20] Gonabadi H, Chen Y, Yadav A, Bull S. Investigation of the effect of raster angle, build orientation, and infill density on the elastic response of 3D printed parts using finite element microstructural modeling and homogenization techniques. Int J Adv Manuf Technol 2022;118:1485–510. https://doi.org/10.1007/s00170-021-07940-4.

[21] Baharlou E, Ma J. Effect of raster orientation on large-scale robotic 3D printing of short carbon fiber-reinforced PLA composites. Addit Manuf Lett 2025;13. https://doi.org/10.1016/j.addlet.2025.100276.

[22] Porima. Porima Polimer Teknolojileri A.Ş. https://porima3d.com/products/porima-abs-filament (accessed June 20, 2025).

[23] International A. ASTM D3039 / D3039M - 17 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials 2017. https://doi.org/10.1520/D3039_D3039M-17.