Analysis of Strength, Durability, Stability, and Fatigue Parameters of Furniture Doors and Drawers Using Engineering Design Method

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Mechanical behavior properties were investigated for cabinet-type cabinet doors in kitchen furniture and drawer bottoms and joints used as storage areas under load in accordance with relevant standards (BS EN 16122). In the first stage, values physical and mechanical for particle board (PB) and medium-density fiberboard (MDF) were determined. According to the test results in the second stage, it was determined that the doors assembled using a torque of 1.3 N/m in the door tests were less deformed than those assembled with 0.63 N/m. According to the finite element analysis and real test results carried out in the final stage, it has been determined that the vertical loading analysis applied on the doors coincides with the real experiments by 85%, horizontal loading by 84%, and slam shut by 50%. The doors didn't pass the final stage durability test in real experiments, and the analysis results revealed that the deformation areas were the same as for real experiment. In the drawers; strength 85%, displacement 84%, and slam shut 94% overlap are represented. The drawers completed the durability test in real experiments, and in the analysis, it was determined that the deformation that occurred under high stresses was in the same areas.

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INTRODUCTION

Wooden materials and wood-based materials form an important component of furniture and furniture construction design. Engineering design is the process of optimally determining the ergonomic criteria, materials used, construction techniques, and technologies used in furniture production.

Knowing the behavior of the materials involved in the formation of the furniture product against physical and mechanical effects provides technical, aesthetic, and economic benefits to designers, manufacturers, and users. In a study on the variation of properties of industrial particleboards, 3/8-inch particleboard was obtained for evaluation from seven different sources that commonly supply the same kitchen cabinet manufacturer (Cassens *et al.* 1994). The following properties were investigated for each of the sources: Young's modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB), surface bond strength, screw withdrawal from both the face and the edge, density, linear expansion, and moisture content (MC). Pinchevska *et al.* (2021) states that the durability of furniture products designed from medium-density fiberboard in real conditions requires preliminary evaluation, and they suggested using the kinetic theory of solid strength, which has been previously validated for particleboard. The results of the calculations correspond to the weighted average service life of furniture for kitchen applications.

Assessment of the structural safety of furniture also requires knowledge of the strength of the parts and assemblies that make up the furniture. In general, wooden furniture under loading experiences deformation in the fasteners and the element itself. Therefore, the design of the fastener is at least as important as the design of the element strength (Wang and Lee 2014). In wood-based furniture construction, it’s important to employ appropriate joint elements. Various structural errors can occur when a proper joinery is ignored (Haftkhani *et al.* 2011; Smardzewski 2015).

Some furniture is installed and fixed with fasteners (rails and hinges) that guarantee strength and durability. In many furniture factories, different slides for drawers and a wide variety of hinges for doors are used. In literature research, there have been few studies that have determined the assembly techniques of such important fasteners (Zhou *et al.* 2012).

Sert (2018) used medium-density fiberboard (MDF) in his master's thesis and carried out mechanical experiments on 80 cm kitchen cabinets with two hinges. The results revealed that MDF has a higher load carrying value than particle board (PB) material. Erdinler *et al*. determined the deflection performance of wooden cabinet doors during opening and closing by using different material types, opening-closing angle, and load force. Medium-density fiberboard and PB, both melamine faced, were used as two different material types. The results showed that the effects of material type, angle, load force, and the mean between the material type and load force were significant, and they reported that the deflection value increased as the loading force increased.

Smardzewski *et al.* (2014) investigated the strength and rigidity of doors by observing the effect of the gaps between concealed hinges as well as the diameter of the screws mounting these hinges. They also examined the distribution of the results according to real tests by applying the numerical analysis method. According to the results, as the distance between the hinges increased, the door rigidity increased. Smardzewski and Majewski (2013) tested different hinge and drawer rails, and the mounting methods of wood, and plastic screws on panels. Different torque values are considered for screwing elements. According to the results, the advantageous screw and torque parameters were determined. It should be 1,342 N/m moment value with the mounting plates of the drawer slides and hinges and the screws placed in plastic sleeves on the furniture body. Smardzewski and Majewski (2013) determined the effect of insertion values as well as sleeves and connecting rings on the strength and durability of drawer slides. Those authors revealed that the maximum deviations that can be accepted in industrial practice for door working loads vary between 1.97 mm and 4.8 mm.

New innovative fasteners have been developed with original designs and user-friendly installation and disassembly methods. Computer simulations using the finite element method (FEM) have been employed to model these fasteners (Krzyżaniak *et al.* 2021).

Recent studies have shown that computer software, especially finite element method (FEM), is being used in the structural analysis of furniture systems. Some studies evaluated strength properties of dowel-joined sofa frames (Kasal 2006), load-bearing capacity of L-shaped furniture self-locking frame connections (Gric *et al.* 2017), and connections modeled as objects made of polylactic acid (PLA) (Kryzniak *et al.* 2020). Several studies focused on the analysis of furniture products made of wood (Tankut *et al.*

2014), the strength of corner dowel-shaped joints (Ke *et al.* 2016), chair tests (Laemlaksakul 2008; Hu *et al*. 2019; Diler *et al*. 2023), the table joint test (Seker and Koc 2023), furniture frames (Colakoglu and Apay 2012), screw connection design (Hu *et al.* 2023), furniture sandwich frames (Matwiej *et al.* 2022), sofa tests (Kuskun *et al.* 2020), honeycomb furniture panels (Smardzewski and Tokarczyk 2024), and wooden sandwich panels with auxetic core for furniture, including experimental and numerical analysis (Zhong *et al*. 2023).

Smardzewski and Ożarska (2005) created a mathematical model of a semi-flexibly connected wood screw and a numerical model of the cabinet furniture structure using the same materials. In addition, the authors developed a mathematical and numerical model of a confirmation type semi-rigid corner fastener loaded with a bending moment using the FEM.

Simek and Sebera (2010) focused on demonstrating the use of advanced technology in the furniture industry. They stated that computer aided engineering (CAE) represented by FEM and computer numerical control (CNC) technologies are key tools.

Zhou *et al.* (2012) determined the maximum deflection values and strains for furniture doors with varying hinge distribution configuration using FEM. Additionally, considering the elastic properties of the wood-derived materials used, the researchers used an experimental design method to determine the optimum number of hinges and the distance between them. The experimental design method has begun to be used in many areas where wood and wood-based materials are used (Hazir *et al.* 2019; 2020).

This study aimed to investigate the mechanical behavior properties of cabinet-type cabinet doors in kitchen furniture and drawer bottoms and joints used as storage areas (the joints of the front, left-right side, and rear parts) under load in accordance with relevant standards (BS EN 16122). Additionally, it aimed to model them using the SolidWorks design program to determine how accurately the behavior can be represented through experimental (real) and finite element structural analysis programs. In the literature review, finite element integration, especially with door and drawer performance tests, was not found. As a working hypothesis, it is expected that deformation will happen consistently in the similar manner as the tightening is fixed on screws. These investigations facilitate further research into optimizing the cabinet-type cabinet doors in kitchen furniture and drawer bottoms and joints used as storage areas furniture industry.

EXPERIMENTAL

The door and drawer, which constitute the sub-module of the kitchen model most preferred by customers in a large-scale company, were included in the scope of the three-stage study.

Kitchen Cabinet Doors and Drawers

In the first stage, the physical (density, moisture, swelling due to water intake, thickness) and mechanical (bending resistance, modulus of elasticity in bending, vertical pulling, screw retention) properties of MDF and PBs from which the furniture will be made were determined.

The kitchen wooden cabinet doors of MDF and PB with dimensions of 800 mm × 650 mm × 18 mm and typical wooden cabinet drawers of MDF and PB with dimensions of 250 mm × 650 mm × 18 mm were chosen to be investigated. A total of thirty-two cabinet doors (15 MDF-15PB) and thirty-two drawers (15 MDF-15PB) manufactured with two different materials were tested. The Tiamos type hinge had a 48 mm axis, 110 degrees, 0 crank, and 5 mm base. Hinges were spaced at 430 mm in accordance with widely employed industrial practice. The NovaPro type runners dimensions were 630 mm × 500 mm. Then, at the center of sample faces, pilot holes measuring 4 × 8 mm (diameter × depth) were drilled for all samples. Hinges and runners were fixed to doors, drawers, and body sides using Φ3.5 × 18 mm screws in the these pilot holes. A diagram indicating how the kitchen furniture doors and drawers were supported by hinges and runners is shown in Fig. 1.

Fig. 1. Doors and drawers were supported by hinges and runners

The boards were sized as the cabinet, door, and drawer parts that make up the kitchen furniture. Screws were driven in with the assistance of industrial automatic screwdrivers equipped in a clutch.

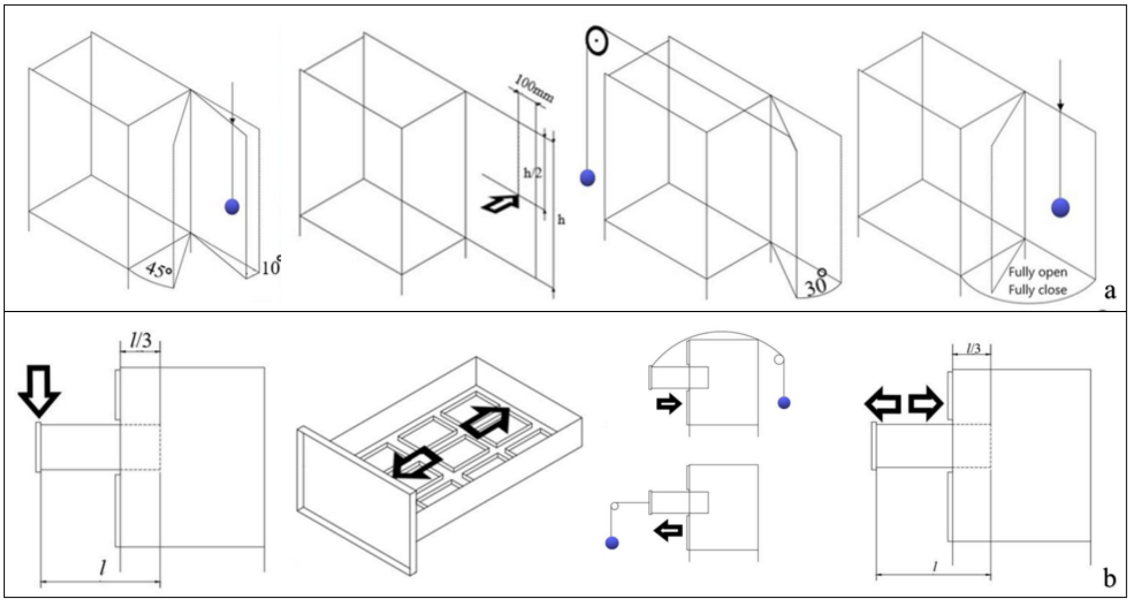

Fig. 2. Test setup: (a) doors, (b) drawers

The clutch was set in such a way as to obtain two different values of drive-in moment: maximal, commonly employed in selected furniture factory and recommended which guaranteed appropriate tightening of screw once the clutch was activated. The applied value of moment was 1.342 Nm, while the recommended by producers value amounted to 0.623 Nm (Smardzewski and Majewski (2013). So sized furniture parts were assembled at the determined screw torque level (1.3 to 0.63 N/m) and prepared for tests.

Test Method for Doors and Drawers

In the second stage, door tests (vertical loading, horizontal loading, slam shut, durability) and drawer tests (strength, displacement, slam shut, durability in extension elements) were performed in four sections. Displacement (deflection) and deformation values were measured. Opening and closing was performed using a durability and stability furniture testing equipment machine (Tumke, Istanbul, Turkey). The study was based on the BS EN 16122 (2012) standard. The experimental designs of the tests applied for the doors and drawers are as shown in Tables 1 and 2. In real use, products do not have a systematic loading history and become deformed and out of use when the strength is exceeded. The visuals of each test performed according to the experimental designs were made separately for the door (a) and drawer (b), as shown in Fig. 2.

Table 1. Door Tests Experimental Design

Material	Torque (N/m)	Number of Samples	Test Name	Cycle	Test Level				
					1	2	3	4	5
MDF	0,63	15	Vertical load of pivoted doors	Mass (kg), 10 cycle	10	15	25	30	45
	1.30								
PB	0.63								
	1.30								

MDF	0.63	15	Horizontal load of pivoted doors	Force (N), 10 cycle	-	50	60	70	80
	1.30								
PB	0.63								
	1.30								
MDF	0.63	15	Slam shut of pivoted doors	Mass (kg) 10 cycle	2	2	3	4	6
	1.30								
PB	0.63								
	1.30								
MDF	0.63	15	Durability of pivoted doors	Cycle	10. 000	20. 000	40. 000	80. 000	160. 000
	1.30								
PB	0.63								
	1.30								

Test level: The type of use that might be expected from furniture in relation to the five test levels.

Table 2. Drawers Tests Experimental Design

Material	Torque (N/m)	Number of Samples	Test Name	Cycle	Test Level				
					1	2	3	4	5
MDF	0.63	15	Strength of extension elements	Mass (kg), Force (N)	2.5 100	2.5 150	3.5 250	6.5 300	8 450
	1.30								
PB	0.63								
	1.30								
MDF	0.63	15	Displacement of extension element bottoms	Mass (kg), Force (N)	2.5 30	2.5 40	3.5 60	6.5 70	8 80
	1.30								
PB	0.63								
	1.30								
MDF	0.63	15	Slam shut and open of extension elements	Slum open 5kg	2	2.3	2.6	2.9	3.2
	1.30				1.2	1.5	1.7	2	2.2
PB	0.63			Slum shut 35kg	2	2.3	2.6	2.9	3.2
	1.30				1.2	1.5	1.7	2	2.2
MDF	0.63	15	Durability of extension elements	Cycle	10. 000	20. 000	40. 000	80. 000	160. 000
	1.30								
PB	0.63								
	1.30								

Structural Analyses with FEM Doors and Drawers

In the final stage, all the parts that make up the samples (cabinet, door, drawer, fasteners) were three-dimensionally modeled and assembled in the design and assembly program (SolidWorks) (Fig. 3).

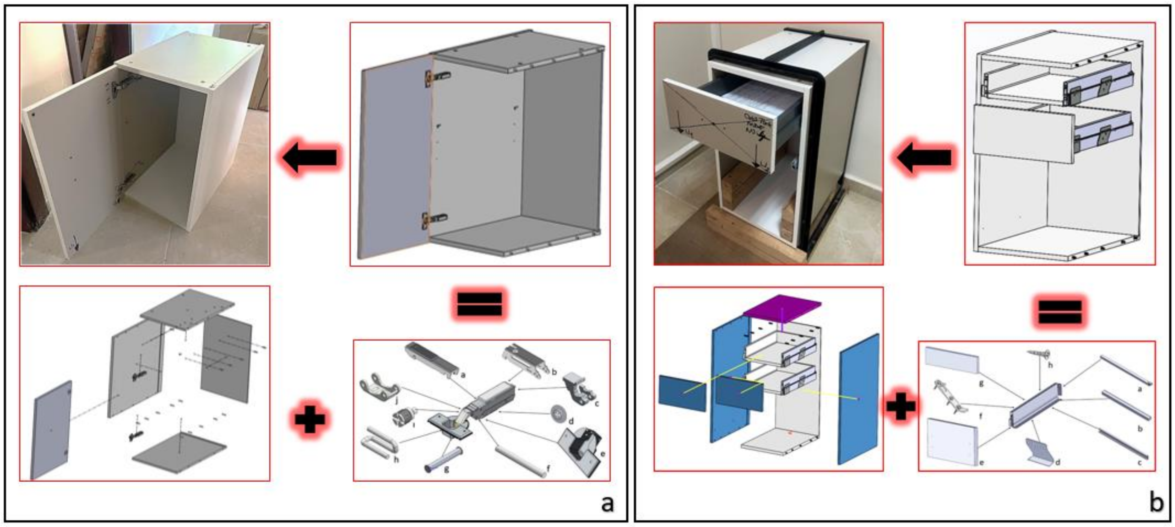

Fig. 3. Design and assembly for (a) doors and (b) drawers

The modeled modules were created like the tests performed in real experiments, and the finite element method (ANSYS Workbench 21) was used for numerical solutions. While the doors and drawers showed resistance to forces in some real tests, in others they did not, and the test was completed. In this way, drawers and doors need to be defined in detail on the virtual platform. For this purpose, four types of finite element models were prepared to approximate the real performance test results. Finite element model all type is shown in Fig. 4.

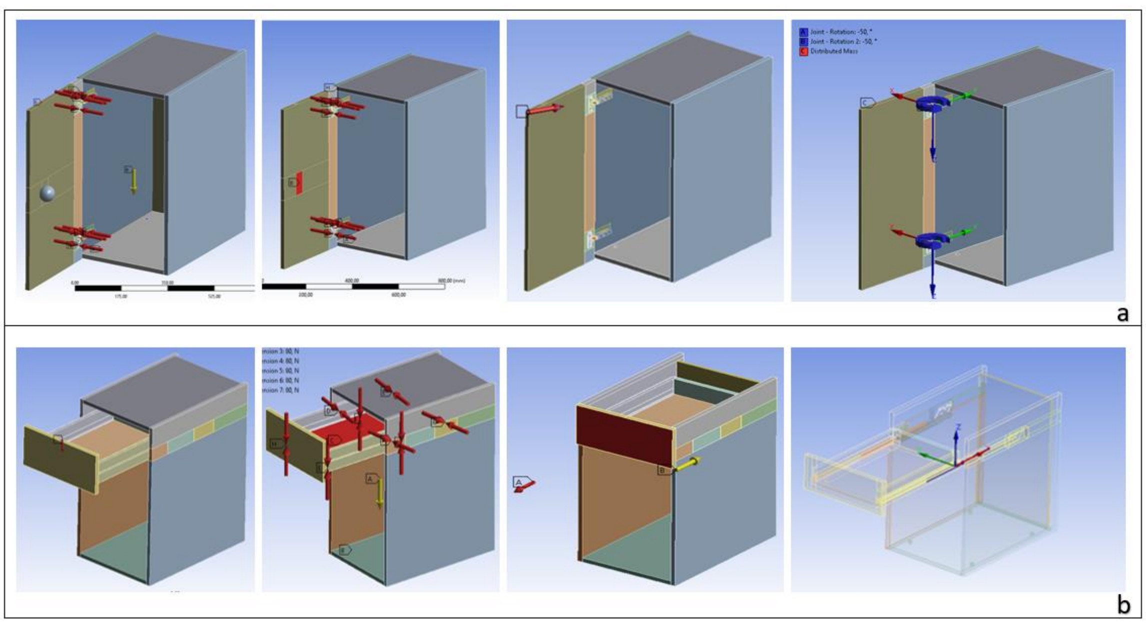

Fig. 4. FEM all type for (a) doors, (b) drawers

In FEM analyses, as in real tests, the weight, number of opening-closing, and force application in Tables 1 and 2 were applied. In four test types, static analysis for test 1 and 2, transient analysis for test 3, and fatigue analysis for test 4 were applied in both modules. The initial results of the MDF and PB materials used in the analysis are described in the materials section. Since the features of the rails and hinges were made of the same metal (MOE; 2000MPa, density; 7580g/cm3 and Poisson Ratio), it was determined as 0.48 mm. In both modules, a fixed support was given from the part resting on the ground and different torque values were defined in the analysis. Rotating contacts that provide opening and closing functions to the hinges and contacts that provide back and forth movement to the rails were also defined. The results were recorded on the deflection amount at U1 and U2 points for the doors and U1, U2, U3 for the drawers, and the approximation with real tests was demonstrated.

RESULTS AND DISCUSSION

Statistical Analysis Results by Deflection Value for Doors and Drawers

In the first stage, values such as density (0.63 kg/m³, 0.75 kg/m³), moisture (7.8%, 5.8%), swelling due to water absorption thickness (16.4%, 5.4%), bending resistance (13.9 N/mm², 29.4 N/mm²), modulus of elasticity in bending (6083 N/mm², 6129 N/mm²), tensile strength in the vertical direction (0.32 N/mm², 0.40 N/mm²), and screw holding resistance (1092 N/mm², 1561 N/mm²) for PB and MDF were determined.

Within the scope of the study, the test results of the cover modules used in kitchen furniture were evaluated at separate stages for each test method. In the final stage, the actual experimental results were statistically defined.

Table 3. Results of ANOVA for MDF and PB Material Doors Test Results

Material	Deflection (mm)	Torque (N/m)	Test 1 (Mass/kg)					Test 2 (N)			Test 3 (Mass/N)					
			10	15	25	30	45	50	60	70	80	2	2	3	4	6
MDF	U1	1,3	0.34 (0.05)*	0.50 (0.05)*	0.70 (0.08)*	0.90 (0.08)*	1.12 (0.03)*	0.14 (0.05)*	0.17 (0.07)*	0.20 (0.10)*	0.23 (0.11)*	0.27 (0.10)*	0.29 (0.12)	0.34 (0.12)	0.38 (0.07)*	0.6 (0.14)*
		0.63	0.43 (0.05)*	0.60 (0.05)*	0.84 (0.08)*	1.02 (0.08)*	1.16 (0.03)*	0.16 (0.05)*	0.21 (0.07)*	0.22 (0.10)*	0.25 (0.11)*	0.28 (0.10)*	0.32 (0.12)	0.35 (0.12)	0.39 (0.07)	0.66 (0.14)
	U2	1.3	0.30 (0.04)*	0.47 (0.05)*	0.62 (0.04)*	0.81 (0.05)*	0.96 (0.05)*	0.12 (0.07)*	0.17 (0.10)*	0.18 (0.08)	0.20 (0.05)	0.21 (0.12)*	0.24 (0.12)*	0.26 (0.12)*	0.29 (0.13)*	0.54 (0.14)*
		0.63	0.36 (0.04)*	0.57 (0.05)*	0.70 (0.04)*	0.92 (0.05)*	1.05 (0.05)*	0.15 (0.07)*	0.19 (0.10)*	0.19 (0.08)	0.22 (0.05)	0.22 (0.12)*	0.25 (0.12)*	0.28 (0.12)*	0.3 (0.13)*	0.57 (0.14)*
PB	U1	1.3	0.38 (0.03)	0.60 (0.11)	0.79 (0.08)*	1.01 (0.09)*	1.23 (0.17)*	0.22 (0.14)*	0.24 (0.14)*	0.28 (0.14)*	0.32 (0.15)*	0.28 (0.14)	0.34 (0.14)	0.4 (0.13)	0.48 (0.13)	1.1 (0.13)
		0.63	0.48 (0.04)	0.63 (0.05)	0.88 (0.03)*	1.27 (0.03)*	1.83 (0.18)*	0.23 (0.14)*	0.27 (0.14)*	0.29 (0.16)*	0.33 (0.16)*	0.3 (0.14)	0.38 (0.14)	0.44 (0.13)	0.5 (0.13)	1.12 (0.13)
	U2	1.3	0.36 (0.03)	0.53 (0.04)	0.74 (0.04)*	0.96 (0.04)*	1.28 (0.16)*	0.16 (0.12)*	0.20 (0.12)*	0.24 (0.13)*	0.26 (0.13)*	0.23 (0.14)	0.32 (0.14)	0.34 (0.14)	0.38 (0.13)	1 (0.13)
		0.63	0.41 (0.05)	0.56 (0.07)	0.81 (0.07)*	1.14 (0.08)*	1.70 (0.14)*	0.18 (0.12)*	0.22 (0.12)*	0.24 (0.13)*	0.26 (0.13)*	0.3 (0.14)	0.32 (0.14)	0.36 (0.14)	0.41 (0.13)	1.1 (0.13)

Mean ( ), standard deviation (*), term is significant with a 95% reliability interval.

Table 4. Results of ANOVA for Test 1 and 2 Results of MDF and PB Material Drawers

Material	Deflection (mm)	Torque (N/m)	Test 1 (Mass/N)					Test 2 (Mass/N)				
			100N/ 2,5kg	150N/ 2.5kg	250N/ 3.5kg	300N/ 6.5kg	450N/ 8.5kg	30N/ 2.5kg	40N/ 2.5kg	60N/ 3.5kg	70N/ 6.5kg	80N/ 8kg
MDF	U1	1.3	0.29 (0.02)*	0.34 (0.03)*	0.56 (0.02)*	0.65 (0.03)*	0.95 (0.04)*	0.16 (0.04)*	0.19 (0.04)*	0.23 (0.03)*	0.25 (0.04)*	0.28 (0.05)*
		0.63	0.29 (0.02)*	0.38 (0.03)*	0.58 (0.02)*	0.80 (0.03)*	0.96 (0.04)*	0.18 (0.04)*	0.21 (0.04)*	0.24 (0.03)*	0.26 (0.04)*	0.29 (0.05)*
	U2	1.3	0.29 (0.03)*	0.35 (0.02)*	0.58 (0.02)*	0.66 (0.04)*	0.97 (0.03)*	0.18 (0.04)*	0.19 (0.05)*	0.24 (0.06)*	0.26 (0.07)*	0.29 (0.09)*
		0.63	0.31 (0.03)*	0.40 (0.02)*	0.59 (0.02)*	0.82 (0.04)*	0.97 (0.03)*	0.19 (0.04)*	0.22 (0.05)*	0.26 (0.06)*	0.27 (0.07)*	0.30 (0.09)*
	U3	1.3	0.14 (0.02)	0.18 (0.03)	0.33 (0.03)*	0.36 (0.04)*	0.51 (0.04)*	0.11 (0.03)*	0.13 (0.03)*	0.14 (0.03)*	0.15 (0.05)*	0.17 (0.05)*
		0.63	0.16 (0.02)	0.23 (0.03)	0.34 (0.03)*	0.36 (0.04)*	0.52 (0.04)*	0.12 (0.03)*	0.14 (0.03)*	0.15 (0.03)*	0.16 (0.05)*	0.18 (0.05)*
PB	U1	1.3	0.34 (0.01)	0.44 (0.01)	0.67 (0.01)	0.78 (0.01)	0.95 (0.01)	0.19 (0.01)	0.20 (0.02)	0.25 (0.02)	0.27 (0.02)	0.29 (0.02)
		0.63	0.36 (0.02)	0.46 (0.01)	0.67 (0.02)	0.81 (0.01)	0.96 (0.01)	0.20 (0.01)	0.21 (0.02)	0.27 (0.02)	0.29 (0.02)	0.31 (0.02)
	U2	1.3	0.36 (0.02)	0.45 (0.01)	0.68 (0.01)	0.80 (0.01)	1.17 (0.01)	0.19 (0.02)	0.21 (0.02)	0.27 (0.02)	0.29 (0.02)	0.31 (0.03)
		0.63	0.37 (0.02)	0.47 (0.01)	0.70 (0.02)	0.82 (0.01)	1.21 (0.02)	0.21 (0.02)	0.23 (0.02)	0.28 (0.02)	0.30 (0.02)	0.34 (0.03)
	U3	1.3	0.18 (0.02)	0.28 (0.01)	0.38 (0.01)	0.44 (0.01)	0.60 (0.01)	0.12 (0.02)	0.13 (0.01)	0.15 (0.02)	0.17 (0.02)	0.20 (0.03)
		0.63	0.20 (0.02)	0.28 (0.01)	0.39 (0.01)	0.45 (0.01)	0.62 (0.01)	0.23 (0.02)	0.15 (0.01)	0.17 (0.02)	0.19 (0.02)	0.24 (0.03)

Mean ( ), standard deviation (*), term is significant with a 95% reliability interval

Table 5. Results of ANOVA for Test 3 and 4 Results of MDF and PB Material Drawers

Mat.	Def. (mm)	Torque (N/m)	Test 3 (Mass/N) (close)					Test 3 (Mass/N) (open)					Test 4 (Cycle)				
			1.29	1.5	1.78	2	2.26	2	2.3	2.6	3	3.3	10.000	2.0000	40.000	80.000	160.000
MDF	U1	1.3	0.18	0.22	0.27	0.31	0.36	0.46	0.49	0.52	0.55	0.58	0.80	0.82	0.84	0.86	0.94
			(0.05)	(0.05)	(0.05)	(0.07)	(0.06)	(0.04)*	(0.04)*	(0.05)*	(0.07)*	(0.05)*	(0.06)	(0.02)	(0.07)*	(0.10)*	(0.14)*
		0.63	0.18	0.22	0.28	0.32	0.37	0.46	0.49	0.52	0.55	0.58	0.84	0.86	0.86	0.91	1.26
			(0.05)	(0.05)	(0.05)	(0.07)	(0.06)	(0.04)*	(0.04)*	(0.05)*	(0.07)*	(0.05)*	(0.03)	(0.02)	(0.04)*	(0.08)*	(0.10)*
	U2	1.3	0.18	0.22	0.28	0.31	0.36	0.46	0.49	0.52	0.55	0.58	0.86	0.86	1	1.31	1.74
			(0.05)	(0.04)	(0.05)	(0.06)	(0.07)	(0.03)*	(0.04)*	(0.05)*	(0.05)*	(0.06)*	(0.06)	(0.02)	(0.09)	(0.17)	(0.15)
		0.63	0.18	0.22	0.28	0.32	0.37	0.46	0.49	0.52	0.55	0.58	0.91	0.97	1.04	1.47	2.16
			(0.05)	(0.04)	(0.05)	(0.06)	(0.07)	(0.03)*	(0.04)*	(0.05)*	(0.05)*	(0.06)*	(0.06)	(0.02)	(0.09)	(0.17)	(0.15)
	U3	1.3	0.07	0.08	0.09	0.10	0.11	0.21	0.23	0.27	0.29	0.31	0.49	0.50	0.55	0.69	0.89
			(0.04)	(0.05)	(0.05)	(0.07)	(0.08)	(0.02)*	(0.03)*	(0.02)*	(0.03)*	(0.02)*	(0.09)	(0.08)	(0.08)*	(0.08)*	(0.13)*
		0.63	0.07	0.09	0.10	0.10	0.12	0.22	0.23	0.28	0.30	0.32	0.60	0.61	0.62	0.69	1.02
			(0.04)	(0.05)	(0.05)	(0.07)	(0.08)	(0.02)*	(0.03)*	(0.02)*	(0.03)*	(0.02)*	(0.09)	(0.08)	(0.08)*	(0.08)*	(0.13)*
PB	U1	1.3	0.20	0.25	0.30	0.35	0.41	0.51	0.54	0.58	0.61	0.65	1.13	1.18	1.30	1.37	1.46
			(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.05)	(0.05)	(0.05)	(0.16)
		0.63	0.21	0.25	0.30	0.36	0.41	0.55	0.54	0.58	0.61	0.65	1.23	1.36	1.38	1.42	1.72
			(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.05)	(0.05)	(0.05)	(0.16)
	U2	1.3	0.21	0.25	0.26	0.36	0.41	0.51	0.54	0.58	0.61	0.65	1.48	1.59	1.60	1.94	2.18
			(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)	(0.15)	(0.15)	(0.18)	(0.19)
		0.63	0.20	0.26	0.30	0.36	0.41	0.52	0.54	0.58	0.61	0.66	1.49	1.84	1.85	2.15	2.53
			(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)	(0.15)	(0.15)	(0.18)	(0.20)
	U3	1,3	0.10	0.11	0.12	0.14	0.15	0.22	0.26	0.28	0.31	0.35	0.65	0.77	1.04	1.23	1.71
			(0.02)	(0.02)	(0.03)	(0.04)	(0.03)	(0.01)	(0.03)	(0.02)	(0.04)	(0.02)	(0.06)	(0.05)	(0.05)	(0.08)	(0.11)
		0.63	0.10	0.11	0.12	0.14	0.16	0.25	0.27	0.29	0.32	0.36	0.73	0.85	1.09	1.34	1.84
			(0.02)	(0.02)	(0.03)	(0.04)	(0.03)	(0.01)	(0.03)	(0.02)	(0.04)	(0.02)	(0.06)	(0.05)	(0.05)	(0.08)	(0.12)

Mean ( ), standard deviation (*), term is significant with a 95% reliability interval

The factorial design and analysis of variance (ANOVA) were employed to determine the main effect and two-way interaction effects with Minitab Software. Values of F and p-values of "prob > F" are lower than 0.05 showing that the equation terms are significant. The variables were effective factors on the deflection values. The model performance parameters were found as 95.55% (R-square) and 93.46% (Adj-R-square). The result of ANOVA for doors is given in Table 3 (MDF and PB material).

The factorial design and ANOVA were employed to determine the main effect and two-way interaction effects. Values of F and p-values of "prob > F" are lower than 0.05 showing that the equation terms are significant. The variables were effective factors on the deflection values. The model performance parameters were found as 92.55% (R-square) and 93.47% (Adj-R-square). The ANOVA results are given in Tables 3, 4, and 5.

According to the actual test results carried out in the second stage, it was determined that the doors assembled using a torque of 1.3 N/mm in the door tests were less deformed than those assembled with 0.63 N/mm. Additionally, throughout the tests, MDF doors were more durable than PB doors, and the situation did not change in the drawer tests. The significance levels of the torque, material, and torque*material variables were also statistically evaluated and demonstrated separately for each test. The doors did not pass the final test, but the drawers did.

Deflection Values and Damage Symptoms for Kitchen Cabinet Doors and Drawers

According to the actual test results, the test was terminated before the doors could complete the fourth test method. The results determined that the doors assembled using a torque of 1.3 N/m in the door tests were less deformed than those assembled with 0.63 N/m. Additionally, throughout the tests, MDF doors were more durable than PB doors, and the situation did not change in the drawer tests. The final version of randomly selected test results for each module is shared for cabinets (Fig. 5) and drawers (Fig. 6).

The most frequent damage symptom of doors was the pulling out of connecting hinges from both PB and MDF. The figures show the deformation of bottom and top hinges, and the deformation of door and failure, respectively. In the case of hinges, mounting plates of the top hinge usually were pulled out from MDF and PB. The deformation values of the cabinet doors were measured by displacement measurement device from the cabinet doors bottom as the deflection occurred after each load, mass, and cycle.

Supporting this result, Sert (2018) carried out mechanical experiments on 80 cm kitchen cabinets made of MDF and PB materials with two hinges and found that the load-bearing value of cabinets made of MDF material was higher. In addition, Erdinler *et al*. (2023) determined the bending performance of the covers during opening-closing using different material types and opening-closing angle load and found that the deformation value of MDF covers was lower than PB. One of the results of the lid tests is that the test ends when the hinge breaks or the hinge fails to perform its opening-closing function and the lid falls. The average deflection values were between 2 to 5mm at both deflection points in MDF material and 3 to 7 mm in PB material until the last test. Although there is no study in the literature supporting the PB material result, Smardzewski and Majewski (2014) found similar results in their study, stating that the maximum deviations that can be accepted in industrial application for door working loads range between 1.97 and 4.8 mm.

Fig. 5. Typical deformation (a) MDF doors from 0.63N/m torque, (b) PB doors from 1.3N/m torque

The results of four test methods for each drawer sample were determined statistically, and a significant difference was found between the test samples made of two materials, MDF and PB. With the values of two deflection points measured on the front cover of the MDF material, and the values of the deflection point taken from the middle of the base, lower deformation results were obtained compared to the PB material in which the same test was performed from the same measurement point. It was determined that the average deflection values were between 2.26 to 0.91 mm at both deflection points in MDF material and 3 to 6 mm in PB material until the last test. Although there is no study in the literature supporting the PB material result, Smardzewski and Majewski (2013) found similar results in their study, stating that the maximum deviations that can be accepted in industrial application for door working loads range between 2.2 and 0.82 mm. However, although there are many studies on shelf deflections in literature, no study has been found on drawer bottom deflections such as (Denizli-Tankut *et al* 2003; Ozarska *et al* 2007; Goktas 2004), and it has been determined that the maximum deviations are 0.13 to 0.08 mm for PB and 0.11 to 0.05 mm MDF materials.

The most frequent damage symptom of drawers was the damaging of connecting contact with drawer front cover from both PB and MDF. The figures show the deformation of rails, deformation of drawers, and deflections front cover, respectively. The deflection values of the drawers were measured by displacement measurement device from the drawer's front cover bottom as the deflection occurred after each load, mass, and cycle.

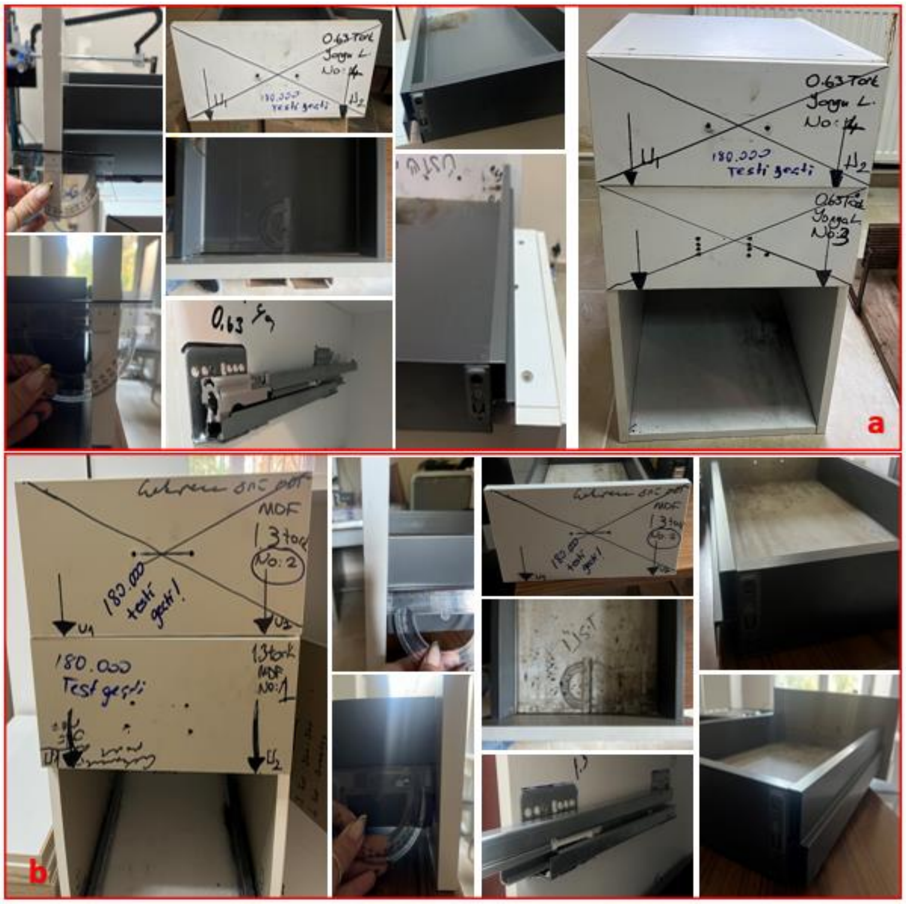

Fig. 6. Typical deformation (a) PB drawers from 0.63N/m torque, (b) MDF drawers from 1.3N/m torque

Finite Element Method Results by Deflection Value for Doors and Drawers

The modeled modules were created like the tests performed in real experiments, and the finite element method (ANSYS Workbench 21) was used for numerical solutions.

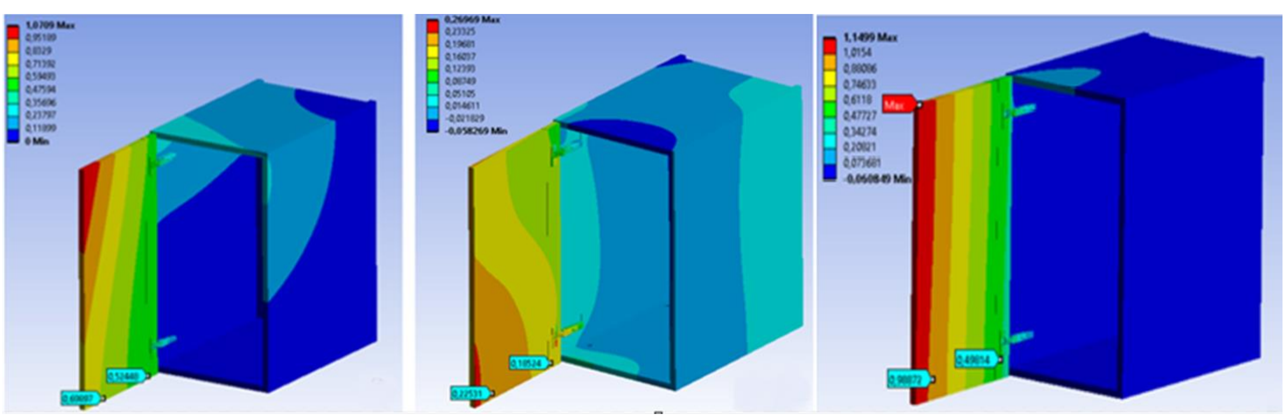

Fig. 7. Test 1,2,3 FEM analysis results

Table 6. Test 1,2,3 FEM Results Applied to MDF and PB Doors

Mate-rial Type	Deflectio-n (mm)	Torqu-e (N/m)	Test 1 (Mass/kg)					Test 2 (N)				Test 3 (Mass/N)				
			10	15	25	30	45	50	60	70	80	2	2	3	4	6
MDF	U1	1,3	0,34	0,46	0,71	0,84	1,20	0,14	0,16	0,18	0,19	0,34	0,57	0,60	0,74	0,76
		0,63	0,35	0,70	0,84	0,85	1,24	0,15	0,16	0,18	0,20	0,39	0,56	0,62	0,75	0,84
	U2	1,3	0,25	0,34	0,52	0,61	0,90	0,16	0,18	0,21	0,22	0,14	0,18	0,22	0,26	0,29
		0,63	0,26	0,36	0,53	0,63	0,92	0,17	0,19	0,21	0,23	0,14	0,19	0,25	0,27	0,36
PB	U1	1,3	0,38	0,56	0,89	1,05	1,25	0,18	0,20	0,23	0,25	0,39	0,50	0,65	0,77	0,90
		0,63	0,41	0,59	0,90	1,15	1,60	0,18	0,21	0,24	0,26	0,49	0,57	0,67	0,80	0,98
	U2	1,3	0,31	0,45	0,74	0,89	0,99	0,22	0,26	0,29	0,32	0,23	0,29	0,39	0,37	0,42
		0,63	0,33	0,47	0,77	0,93	1,29	0,23	0,27	0,30	0,33	0,25	0,32	0,37	0,46	0,49

Table 7. Test 1 and 2 FEM Results Applied to MDF and PB Drawers

Material Type	Deflection (mm)	Torque (N/m)	Test 1 (Mass/N)					Test 2 (Mass/N)				
			100N/ 2.5kg	150N/ 2.5kg	250N/ 3.5kg	300N/ 6.5kg	450N/ 8.5kg	30N/ 2.5kg	40N/ 2.5kg	60N/ 3.5kg	70N/ 6.5kg	80N/ 8kg
MDF	U1	1.3	0.29	0.34	0.57	0.66	0.95	0.17	0.19	0.23	0.23	0.26
		0.63	0.29	0.39	0.57	0.80	0.85	0.17	0.22	0.23	0.24	0.27
	U2	1.3	0.29	0.34	0.57	0.66	0.96	0.17	0.19	0.23	0.24	0.27
		0.63	0.30	0.39	0.57	0.81	0.97	0.17	0.22	0.23	0.24	0.27
	U3	1.3	0.16	0.18	0.34	0.38	0.51	0.11	0.12	0.13	0.14	0.16
		0.63	0.17	0.20	0.34	0.38	0.52	0.12	0.13	0.13	0.15	0.17
PB	U1	1.3	0.34	0.45	0.68	0.79	1.17	0.19	0.21	0.26	0.27	0.30
		0.63	0.34	0.45	0.69	0.80	1.17	0.19	0.22	0.26	0.28	0.30
	U2	1.3	0.34	0.45	0.69	0.81	1.18	0.19	0.22	0.26	0.28	0.30
		0.63	0.34	0.47	0.69	0.82	1.19	0.19	0.22	0.27	0.28	0.30
	U3	1.3	0.18	0.29	0.39	0.44	0.60	0.12	0.13	0.15	0.17	0.19
		0.63	0.20	0.25	0.41	0.45	0.61	0.23	0.13	0.15	0.17	0.19

Table 8. Test 3 FEM Results Applied to MDF and PB Drawers

Material Type	Deflection (mm)	Torque (N/m)	Test 3 (Mass/N) (close)					Test 3 (Mass/N) (open)				
			1.29	1.5	1.78	2	2.26	2	2.3	2.6	3	3.3
MDF	U1	1.3	0.18	0.22	0.27	0.31	0.36	0.46	0.49	0.52	0.55	0.58
		0.63	0.18	0.22	0.28	0.32	0.37	0.46	0.49	0.52	0.55	0.58
	U2	1.3	0.18	0.22	0.28	0.31	0.36	0.46	0.49	0.52	0.55	0.58
		0.63	0.18	0.22	0.28	0.32	0.37	0.46	0.49	0.52	0.55	0.58
	U3	1.3	0.07	0.08	0.09	0.10	0.11	0.21	0.23	0.27	0.29	0.31
		0.63	0.07	0.09	0.10	0.10	0.12	0.22	0.23	0.28	0.30	0.32
PB	U1	1.3	0.20	0.25	0.30	0.35	0.41	0.51	0.54	0.58	0.61	0.65
		0.63	0.21	0.25	0.30	0.36	0.41	0.55	0.54	0.58	0.61	0.65
	U2	1.3	0.21	0.25	0.26	0.36	0.41	0.51	0.54	0.58	0.61	0.65
		0.63	0.20	0.26	0.30	0.36	0.41	0.52	0.54	0.58	0.61	0.66
	U3	1.3	0.10	0.11	0.12	0.14	0.15	0.22	0.26	0.28	0.31	0.35
		0.63	0.10	0.11	0.12	0.14	0.16	0.25	0.27	0.29	0.32	0.36

The final test concluded that the deformation was 3 to 5 mm for MDF and PB materials. The deformation, especially in the hinge and the junction of the hinge and the lid, directly caused the lid to shift (Fig. 7). While 83 to 87 MPa stress was determined for MDF materials when the door was open and 93 to 95 MPa when it was closed, it was concluded that this value increased to 135 MPa on the general part. In PB materials, while the stress was determined as 63 to 65 MPa when the cover was open and 81 to 84 MPa when it was closed, it was concluded that this value increased to 119 MPa on the general part. In real tests, the breakage of the upper hinge (Fig. 8) prevented the completion of the fourth test. Although the stresses in the finite element analysis results were so small, the deformation was high, and the deformation occurred in the same position. This shows that the two results overlapped.

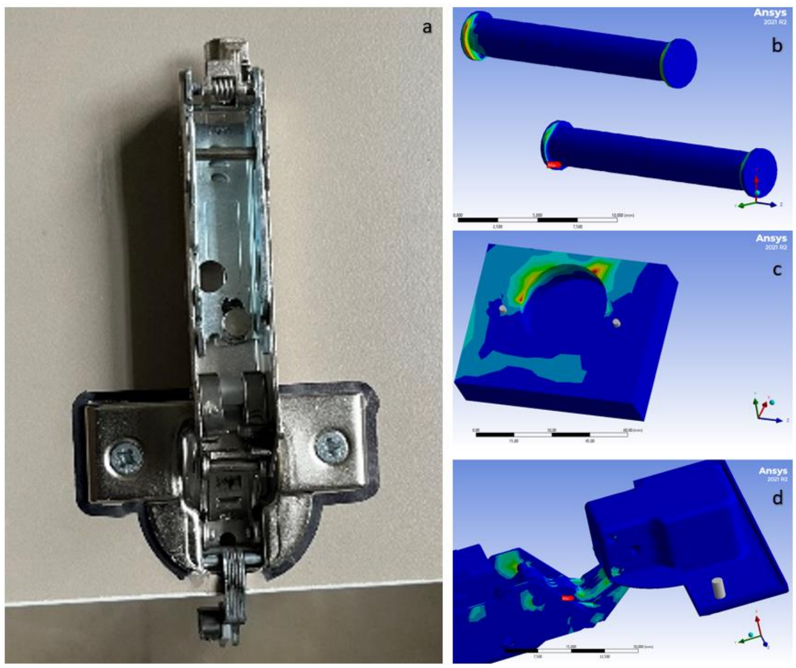

Fig. 8. (a) real hinges test result; (b), (c), (d) FEM hinges analysis result

Similarly, Zhou *et al.* (2012) determined the maximum deflection values of 0.0093 mm and 0.0172 mm (two hours loading) and stresses in furniture doors in varying hinge distribution configuration using FEM. Considering the elastic properties of the wood-based materials used, the researchers suggested this method by conducting experiments to determine the optimum number of hinges and distance, demonstrating its closeness to this method. However, Smardzewski *et al.* (2014) stated that in furniture design, door deflections generally exceeding 0.05 mm can be considered to have no effect on improving proportions or aesthetics. For this reason, the study revealed that the maximum deviations in the operational loads of this stud door will range between 1.12 mm and 7.23 mm, which are possible values according to industrial applications, and similar explanations can be made about the distribution of stresses.

It was concluded that the deformation was 4 to 7 mm for MDF and PB materials as a result of the entire test. The deformation, especially in the rail and component area, directly caused the cover to shift. Table 11 shows the values when it is open and when it is closed, and the observation of deformations in similar places showed that the two results coincided (Fig. 9).

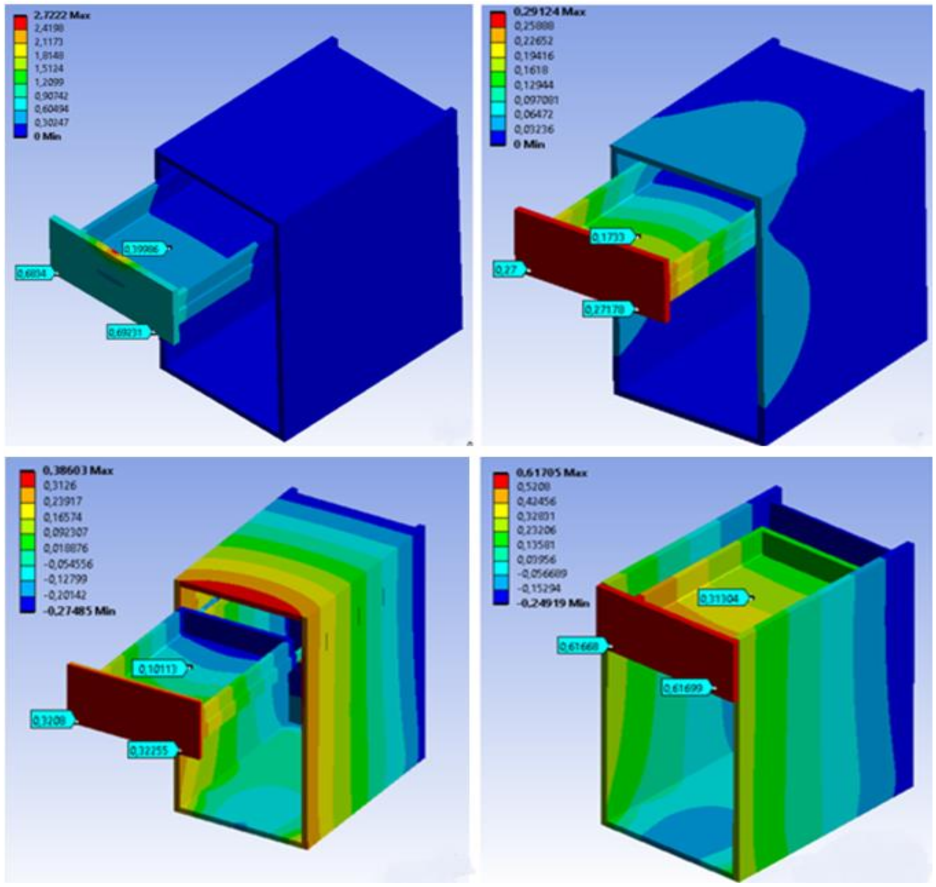

Fig. 9. Test 1, 2, 3 FEM analysis results

Table 9. Strains When the Drawer is Open and When It Is Closed

Mass	Material	Open position	Close Position	General Component
2.5kg	MDF	83-87 MPa	93-95 MPa	395 MPa
	PB	63-65 MPa	81-84 MPa	135 MPa
3.5kg	MDF	250-300 MPa	320-450 MPa	513 MPa
	PB	220-272 MPa	280-420 MPa	482 MPa
6.5kg	MDF	270-326 MPa	332-475 MPa	819 MPa
	PB	240-286 MPa	295-430 MPa	786 MPa
8kg	MDF	290-586 MPa	320-625 MPa	1019 MPa
	PB	260-306 MPa	325-468 MPa	994 MPa

For the actual tests, in cases where the final test was completed, all drawer samples passed the tests. High stress values were observed in the finite element analysis in the last test where fatigue analysis was performed (Table 9) and the observation of deformations in similar places showed that the two results coincided (Fig. 10).

Smardzewski and Klos (2011) modeled the joint substitution stiffness of plate elements subjected to opening and closing. They presented alternative methods for numerical modeling of dowel connection stiffness of plate elements. They found the finite element method to be most suitable for determining the values of this module, detecting, comparing, and improving the deflections of this connection. They argued that the deviation value of the values made through laboratory experiments and numerical calculations ranged between 3 and 4%. Similarly, Cai and Wang (1991) investigated the tensile strength of joints using FEM and analytical methods. Analytical and numerical analyzes were compared with the experimental results obtained within the scope of the study. The consistency level between the analytical method and experiments was 80% and the consistency level between numerical analysis and experiments was 83% structural analysis programs.

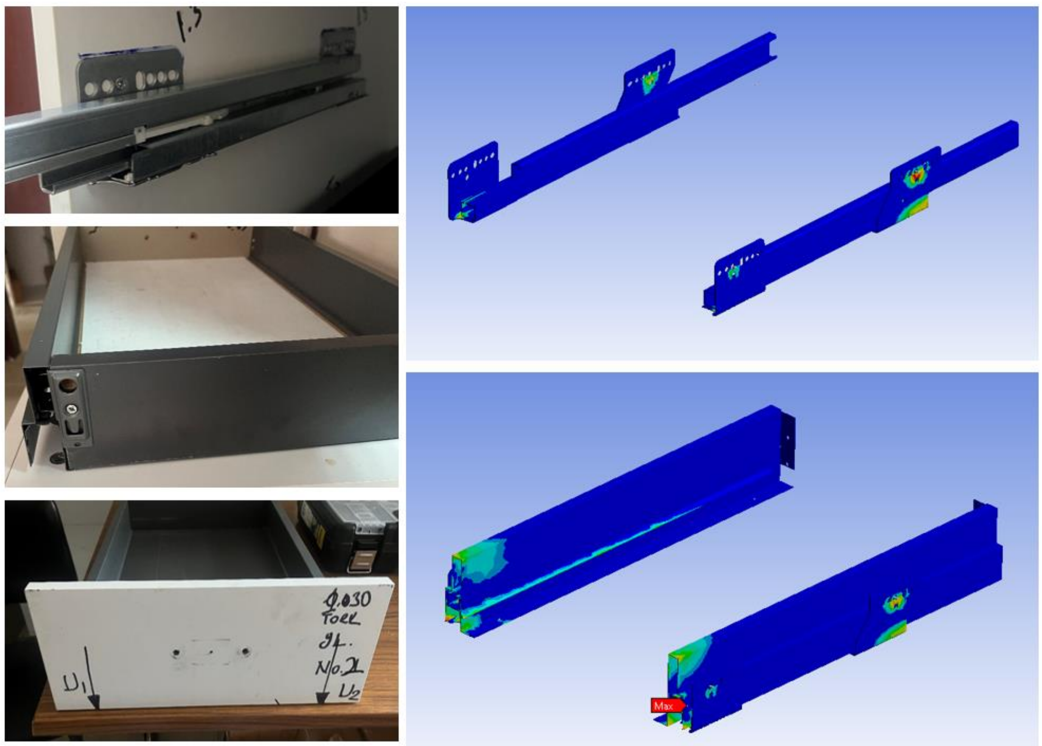

Fig. 10. (a) Real drawers test result; (b), (c), (d) FEM drawers analysis result

According to the finite element analysis and real test results carried out in the last stage, the vertical loading analysis applied on the doors coincided with the real experiments by 85%, horizontal loading by 84%, and slam shut by 50%. The doors did not pass the final stage durability test in real experiments, and the analysis results revealed that the deformation areas were the same. In the drawers, strength was 85%, displacement was 84%, and slam shut was 94% overlap. The drawers completed the durability test in real experiments, and in the analysis, it was determined that the deformation that occurred under high stresses was in the same areas.

The results demonstrated that through the engineering design methodology carried out within the scope of the study, numerical data can be provided to designers, manufacturers, and engineers through design, modeling, and structural analyses before the furniture is produced.

CONCLUSIONS

1. Material type, torque and load variables were determined to be effective relative to deflection values, utilizing variance analysis. Simultaneously, the interaction between material type, load, and torque was significant. Adequacy of models was performed by R-square (R^2) and adjusted R-square (Adj-R^2) values. These values were found to be 92.55% and 93.47%, respectively.
2. In the first stage, values such as density (0.63 kg/m³, 0.75 kg/m³), moisture (7.8%, 5.8%), swelling due to water absorption thickness (16.4%, 5.4%), bending resistance (13.9 N/mm², 29.4 N/mm²), modulus of elasticity in bending (6083 N/mm², 6129 N/mm²), tensile strength in the vertical direction (0.32 N/mm², 0.40 N/mm²), and screw holding resistance (1092 N, 1561 N) for PB and MDF were determined.
3. According to the actual test results carried out in the second stage, it was determined that the doors assembled using a torque of 1.3 N/m in the door tests were less deformed than those assembled with 0.63 N/m. Additionally, throughout the tests, MDF doors were more durable than PB doors, and the situation did not change in the drawer tests. The significance levels of the torque, material, and torque*material variables were also statistically investigated and proven separately for each test.
4. According to the finite element analysis and real test results carried out in the final stage, it was determined that the vertical loading analysis applied on the doors coincides with the real experiments by 85%, horizontal loading by 84%, and slam shut by 50%. The doors did not pass the final stage durability test in real experiments, and the analysis results revealed that the deformation areas were the same. In the drawers, strength was 85%, displacement was 84%, and slam shut was 94% overlap. The drawers completed the durability test in real experiments, and in the analysis, it was determined that the deformation that occurred under high stresses was in the same areas.
5. The results showed that through the engineering design methodology carried out within the scope of the study, numerical data can be provided to designers, manufacturers, and engineers through design, modeling, and structural analyses before the furniture is produced.

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