Evaluation of the Factors Affecting Opening-Closing Performance of Wooden Cabinet Doors

Emine Seda Erdinler, Sedanur Seker,* Ender Hazır, and Kucuk Huseyin Koc

This study determined the deflection performance of wooden cabinet doors during opening and closing by using different material types, opening-closing angle, and load force. The independent variables consisted of material type, opening-closing angle, and load force, and the dependent variable was determined as deflection value. Medium density fiberboard (MDF) and particleboard (PB), both melamine faced, were used as two different material types. Opening and closing angles and directions of forces were performed as directed in BS EN 16122 (2012) and TSE EN 9215 (2005) and the doors were loaded by forces of 300N, 375N and 450N. The factors affecting deflection value and the interaction between them were investigated by multivariate analysis of variance. The results showed that the material type, angle, load force, and the mean between the material type and load force was significant. As the loading force increased, the deflection value increased. As the moisture increased, the deflection value increased, and as the material density increased, deflection value decreased. The adequacy of models was evaluated by the R-square (R^2) and Adjusted R-square (Adj-R2) values. The results for these values were 88.23% and 86.58%, respectively.

DOI: 10.15376/biores.18.1.1384-1397

Keywords: Furniture cabinet door; Joints; Opening-closing performance; Load and deformation; Hinges

*Contact information: Faculty of Forestry, Department of Forest Industry Engineering, Istanbul University - Cerrahpasa, Istanbul, Turkey; *Corresponding author: sedanur.seker@iuc.edu*

INTRODUCTION

Wood materials and wood-based materials are important components of furniture design and construction. Knowing the behavior of the materials involved in the formation of the furniture product against their physical and mechanical effects provides technical, aesthetic, and economic benefits to designers, manufacturers, and users.

As furniture design and construction are much needed in daily life, they are considered an applied art (Wang *et al.* 2014). The strength evaluation of furniture begins at the design phase (Smardzewski *et al.* 2014). Smardzewski and Majewska (2013) emphasize the importance of strength and durability on the functionality for furniture.

In furniture manufacturing, especially designs for storage purposes, the safety of use requires mobile elements to be secured against ejection. This requirement also applies for other elements, *i.e.*, doors, flaps, or covers, referring to their design and structural form. Doors can be fixed into the body part of the cabinet, harmonized with narrow planes of side walls and chambers, or placed on these surfaces. Access to the interior of the body part of the cabinet is possible by turning, sliding, or opening the door (Smardzewski 2015).

As construction components with different techniques, the furniture quality is based on the strength of joints, which have a crucial role (Kasal *et al.* 2016). The joints should always be carefully selected in the construction of wood-based furniture. Various structural failures may occur when a proper connection is overlooked (Haftkhani *et al.* 2011; Smardzewski *et al.* 2015). For this reason, designers need appropriate knowledge to select a suitable combination of components (dimension, geometry, material type) and fasteners (dowels, nails, screws, bolts) (Maleki *et al.* 2017). Vassiliou and Barboutis (2009) determined the tensile strength of screws that form eccentric connections by inserting them as either naked or with plastic sockets to particleboard and medium-density fiberboard. Kowaluk *et al*. (2011) studied particleboards with different densities from specially prepared particles of black locust and willow as an alternative light weight product. The standard mechanical parameters of panels were investigated, and the screw withdrawal resistance and hinge bearing for investigated panels were measured. Except for low density black locust panels, all panels were suitable for use in furniture production.

Demountable fasteners are predominant in cabinet furniture, although they are uncommon in frame furniture (Vassiliou and Barboutis 2005; Efe and Imirzi 2007; Prekrat and Spanic 2009; Ozkaya *et al*. 2010; Yuksel *et al.* 2015; Smardzewski *et al.* 2016; Kucuktuvet *et al.* 2017). Screws and hinges are used in the doors, and these fasteners are deformed by being exposed to loads such as the door.

Researchers have focused their attention on a wide range of subjects such as: reliability of cabinet furniture and their connections, analysis of the impact of screw joint stiffness, and strength on the constructional strength of cabinet furniture (Smardzewski 2004; 2005; Smardzewski and Ozarska 2005; Kasal *et al.* 2008; Smardzewski 2009). These deformations that occur in the fasteners over time affect the strength of the furniture. In addition, the displacements of the doors were investigated in this study.

Ozcifci (2009) evaluated the effects of screw type, layer thickness and pilot hole on the tensile strength of some screws in laminated veneer lumber (LVLs). The highest tensile strength was obtained in oak samples with a coating thickness of 4 mm, bonded with phenol-formaldehyde adhesives for 3.5 x 16 mm screws.

As a result of industrial applications that continue to develop, a wide variety of hinges and fittings are used to provide the rotational movement of a door. The doors in case furniture can be opened by an angle from 110° to 360°, depending on the construction elements (Smardzewski 2015).

Using the finite element method (FEM), Zhou *et al*. (2012) determined the maximal deflection values and strains for furniture doors, at varying configuration of hinge distribution. Considering the elastic properties of the employed wood-derived materials, the researchers proposed a method of determination of the optimal number of hinges and distances between them.

Furthermore, researchers have studied the main assessment criterion of joint strength was the value of the breaking force or bending moment. On the other hand, stiffness has been evaluated on the basis of the deflection value along the direction of load application or on the basis of the value change of the angle between the arms of the joint (Chai *et al*. 1993; Nicholls *et al*. 2002).

In a study on stiffness in furniture doors manufactured from laminated particleboards, Smardzewski *et al.* (2014) investigated the strength and stiffness of doors by observing the impact of spacings between concealed hinges as well as the diameter of screws mounting these hinges. The door stiffness increased together with the increase of distances between hinges.

Hao *et al*. (2020) interpreted the effects of dowel dimension, dowel position, and loading distance on the bending moment capacity with analysis of variance and statistical values. Kamboj *et al*. (2020) performed statistical analyses to determine the effect of the monitored factors and their interactions on the density and elastic stiffness of the joints

In this study, deflection values, as an important indicator of door opening and closing performance, were determined, and the factors affecting deflection values were systematically investigated. At the same time, the effects of density difference and moisture values deflection were analyzed.

EXPERIMENTAL

Cabinet Doors

Typical wooden cabinet doors of Medium Density Fiberboard and Particle Board with dimensions of 1800 mm (height) × 450 mm (width) × 18 mm (thickness) were chosen randomly from the company's production line to investigate. A total of 4 cabinet doors manufactured with two different materials were tested. The cabinet doors were supported by hinges with dimensions of 35 mm (diameter) × 12 mm (height), which were mounted vertically along the door. A diagram showing how the furniture door was supported by hinges is shown in Fig. 1. The star type hinge had a 48 mm axis, 110 degree, 0 crank, and 5 mm base. Hinges were fixed to doors and body sides using Φ3.5 x 13 mm screws. Four screws per hinge were used as two on the door piece and two on the body side piece. Hinges were spaced at 430 mm in accordance with widely employed industrial practice. Figure 1 shows dimensions of individual elements as well as dimensions and spacings between holes for screws.

Fig. 1. Dimensions of samples and mounting holes; hinges

All screws were inserted with commercial screwdrivers equipped in a clutch. The screwdriver was set to achieve a drive-in moment value of 2.4 Nm. The cabinet doors were labelled as MDF 1, MDF 2, PB 1, and PB 2. Accordingly, moisture and density determinations were conducted with 15 small samples taken from each door. Based on Eqs. 1 and 2, moisture determination was performed according to EN 322 (1993), while density determination was performed according to EN 323 (1993),

$$MC = (m_1 - m_2)/m_2 \times 100 \tag{1}$$

$$d = m/V \tag{2}$$

where MC is the moisture content (%), m_1 is the initial mass of the test piece before drying (g), m_2 is the oven dry mass of the test piece (g), d is the density of the test pieces at moisture content for materials (g/cm^3), m is the mass of the test pieces at moisture component for materials (g), and V is the volume of the test pieces at moisture content for materials (cm^3). The moisture content and density for MDF 1, MDF 2, PB 1, and PB 2 were determined as 7.26%, 0.717 g/cm^3; 8.01%, 0.718 g/cm^3; 9.054%, 0.64 g/cm^3; and 8.41%, 0.62 g/cm^3, respectively.

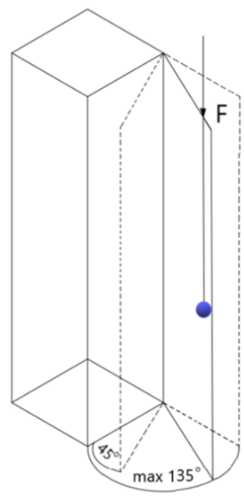

Fig. 2. Loading direction of the door with static vertical force

Test Method for Doors

Figure 2 shows the loading of the door with the specified mass. The load was suspended 100 mm from the edge furthest from the hinge. The door was opened and closed ten full turns (back and forth) from position of 45° from fully closed position to 10° position from fully open position to maximum 135° position with an auxiliary element. Opening and closing was performed by a Durability and Stability Furniture Testing Equipment machine (Tumke, Istanbul, Turkey). The study was based on the BS EN 16122 (2012) standard. However, the TS EN 9215 (2005) standard was followed to reveal the deformations that occur in the door after increasing loads. For this reason, forces of 375 N and 450 N were loaded in addition to 300 N loads and opening from fully closed to 10° angle, from fully closed to 135° angle and additional 10° from 45° from fully closed position are performed in accordance with TS EN 9215 (2005). The cycle was repeated 10 times for each sample. The main criteria of the quality assessment of the examined hardware comprised deformations caused by the applied load force and deflection values of MDF 1, MDF 2, PB 1, and PB 2.

RESULTS AND DISCUSSION

Damage Symptoms and Deflection Values

The most frequent damage symptom of hinges was the pulling out of connecting links from both Particle Board and Medium Density Fiberboard. Tests results for MDF 1, MDF 2, PB 1, and PB 2 are shown in Figs. 3, 4, 5, and 6, respectively. The figures are labelled as ‘a’,’ b’ and ‘c’ illustrating the deformation of bottom hinges, deformation of middle hinges, and deflections, respectively. In the case of hinges, mounting plates of the middle hinge usually were pulled out; less frequently, plates of the bottom hinge from MDF 1 and MDF 2 while the opposite was determined for PB1 and PB2. The deflection values of the cabinet doors were measured using a DEVOTRANS displacement measurement device produce in Turkey from the cabinet door bottoms as the deflection occurred after each load.

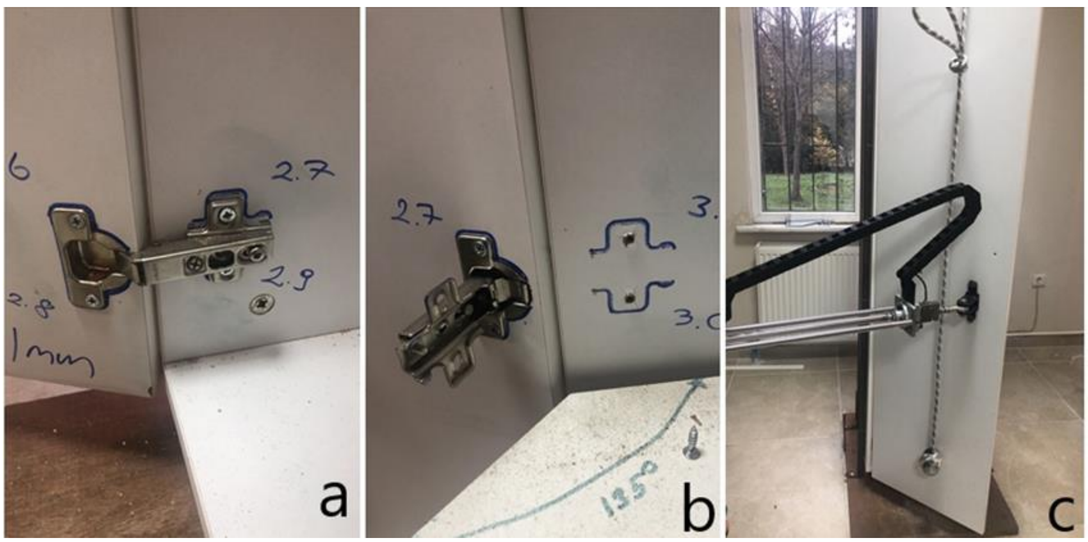

Fig. 3. Typical deformation: (a) bottom hinges, (b) middle hinges, (c) deflection of the door for MDF 1

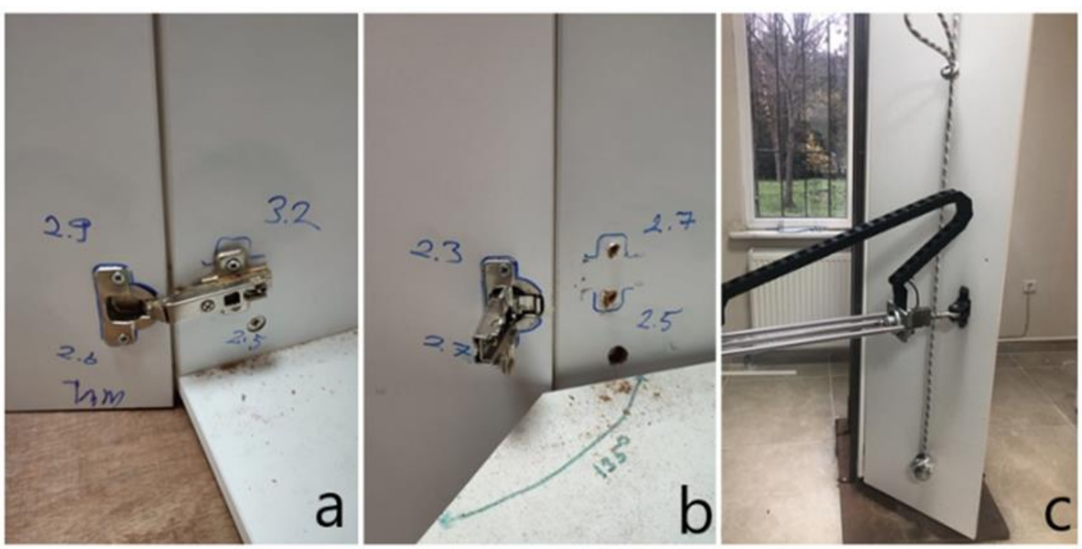

Fig. 4. Typical deformation: (a) bottom hinges, (b) middle hinges, (c) deflection of the door for MDF 2

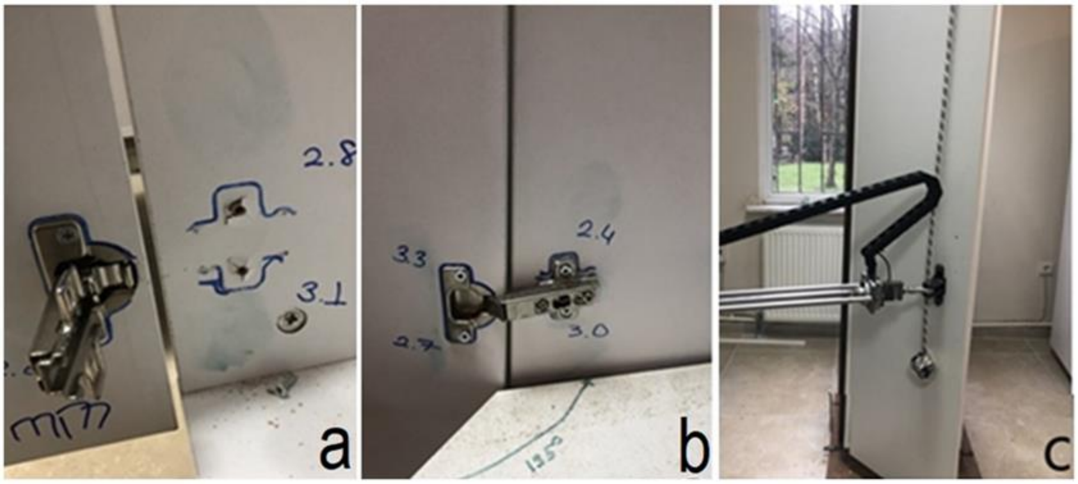

Fig. 5. Typical deformation: (a) bottom hinges, (b) middle hinges, (c) deflection of door for PB 1

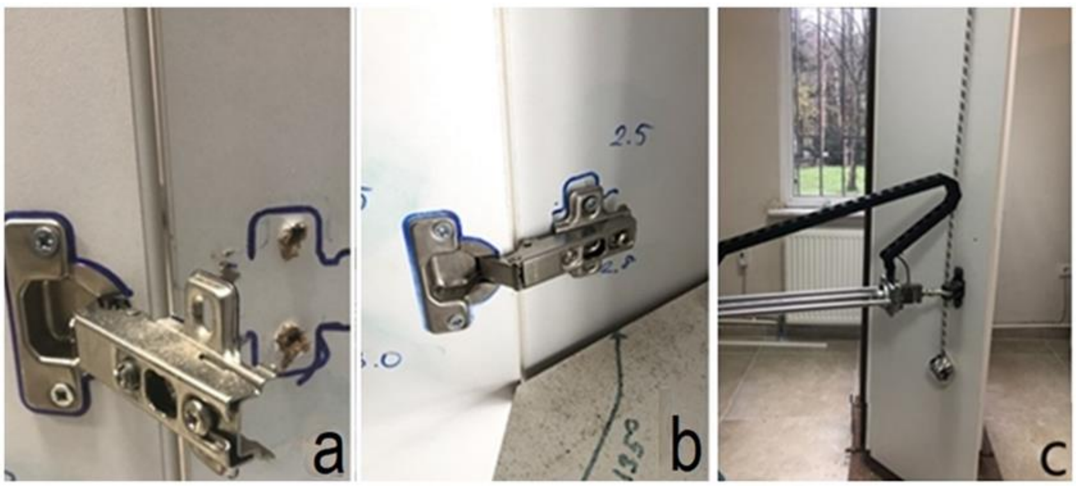

Fig. 6. Typical deformation: (a) bottom hinges, (b) middle hinges, (c) deflection of door for PB 2

Table 1 was created to compare the results statistically. In the table, deflection values are represented as follows: a; from 45° open to 10 to 135° b; from 45° open to 10° more, c; from fully closed to 135°, d; from fully closed to 10°.

Statistical Analyses Results

ANOVA is a parametric statistical method applied to compare the full factorial design technique investigates every possible combination for factor levels at two levels. Other application methods such as t-test and z-test are applied to compare means and the relationship between the factors. However, ANOVA is the best method in cases where more than 2 populations are meant to be compared (Montgomery 1997; Myers *et al*. 2016). Null hypothesis and F-value are given in Equations 3 and 4:

$$H0 : \mu_1 = \mu_2 = \ldots = \mu_a \tag{3}$$

$$H1 : \mu_i \neq \mu_J \text{ for at least one pair}$$

$$F = (SSA/a\text{-}1)/(SSE/N\text{-}a) = MSA/MSE \tag{4}$$

Table 1. Experimental Design of Samples

	Angle(c)	Material type	Load (N)	Deflection Value (mm)
MDF DOOR 1	a	MDF*	300	2.5
	b	MDF	300	2.6
	c	MDF	300	2.6
	d	MDF	300	2.7
	a	MDF	375	2.9
	b	MDF	375	3
	c	MDF	375	3
	d	MDF	375	3.1
	a	MDF	450	3.4
	b	MDF	450	3.5
	c	MDF	450	3.6
	d	MDF	450	3.7
MDF DOOR 2	a	MDF	300	0.8
	b	MDF	300	1
	c	MDF	300	1.2
	d	MDF	300	1.2
	a	MDF	375	1.4
	b	MDF	375	1.5
	c	MDF	375	1.6
	d	MDF	375	1.8
	a	MDF	450	2
	b	MDF	450	2.2
	c	MDF	450	2.2
	d	MDF	450	2.4
PB DOOR 1	a	PB*	300	6
	b	PB	300	6
	c	PB	300	7
	d	PB	300	7.8
	a	PB	375	8.2
	b	PB	375	8.5
	c	PB	375	8.8
	d	PB	375	8.8
	a	PB	450	9
	b	PB	450	9
	c	PB	450	9.2
	d	PB	450	9.2
PB DOOR 2	a	PB	300	5.2
	b	PB	300	5.2
	c	PB	300	6.4
	d	PB	300	6.4
	a	PB	375	6.6
	b	PB	375	6.6
	c	PB	375	6.8
	d	PB	375	7
	a	PB	450	7.2
	b	PB	450	7.2
	c	PB	450	7.4
	d	PB	450	7.4

*MDF: Medium Density Fiberboard; **PB: Particleboard

Table 2. Result of ANOVA for Deflection Tests

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Material type	3	331,142	110,381	2080,47	0,000
Load(N)	2	18,375	9,188	173,17	0,000
Angle(c)	3	2,172	0,724	13,64	0,000
Material type*Load(N)	6	3,438	0,573	10,80	0,000
Material type*Angle(c)	9	0,660	0,073	1,38	0,266
Load(N)*Angle(c)	6	0,738	0,123	2,32	0,078
Error	18	0,955	0,053		
Total	47	357,480			

The null hypothesis is rejected when the F0 is higher than the critical value of Fα,α−1,N−α, where α is the significance level. p-value is less than 0.05, the model variable is significant at 95% confidence level. From Table 2, material type, load, angle, material type*load, resulted as effective factors.

The developed model was evaluated by using normal probability plot, versus fits, histogram, and versus order. In Fig. 7, standardized residuals were scattered with straight line and these residuals resembled a normal distribution.

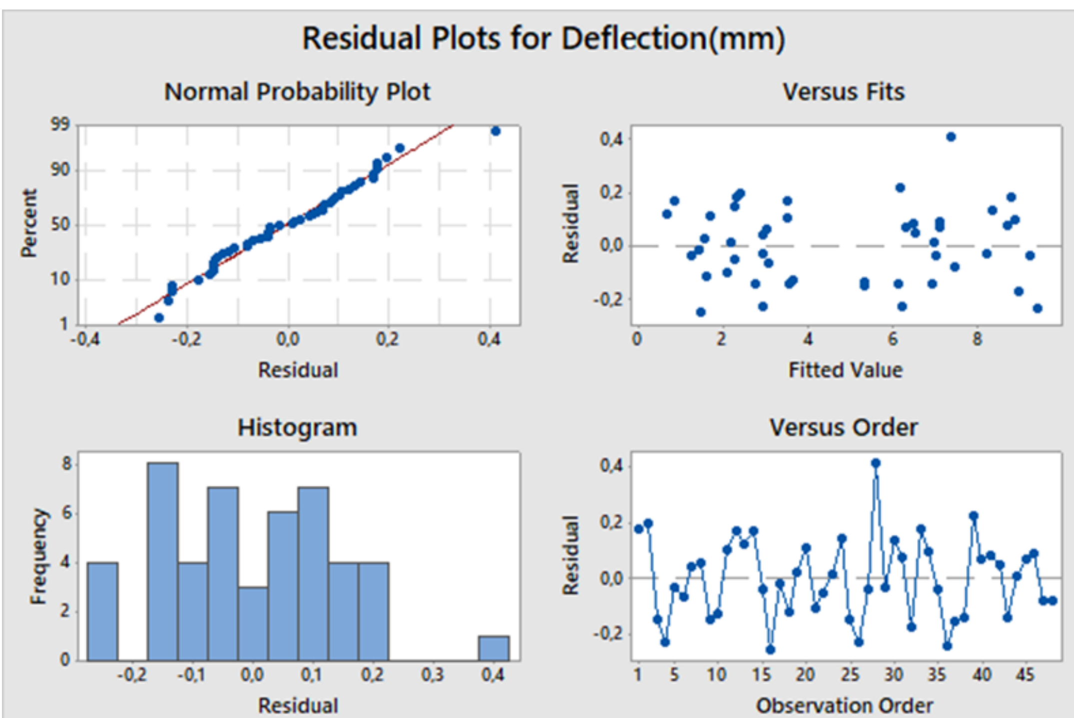

Fig. 7. Normal probability plot, versus fits, histogram and versus order view for developed models

Moreover, there was no systematic error in the appearance consisting of standardized residuals. Standardized residual d_i is given in Eqs. 5 and 6:

$$d_i=e_{ij}/\sqrt{MSE} \tag{5}$$

The residual is explained as:

$$e_i = y_i - \hat{y}_i \text{ , where } i = 1, 2, \ldots, n \tag{6}$$

In Eq. 6, y_i is the observation value and $\hat{y}_i$ is the predicted value. $\sqrt{(MSE)}$ indicates mean error sum of square, and this value is in the range of $-3 \leq d_i \leq 3$. Therefore, the developed model was found as adequate (Myers *et al.* 2009; Saleem *et al.* 2015).

The main effect plot investigated the differences between level means for one or more parameters. The plot of main effects displays the response mean for each parameter level connected by a line. If the main effect plot line is horizontal (parallel to the x-axis), then it has no effect on the output. If the main plot line is not horizontal, then it has an effect on the output. In this study, the effects of material type, load and angle were evaluated to determine the effective factors. According to Fig. 8, the highest deflection value occurred in PB 1 and the lowest deflection value occurred in MDF 2. When loads are assessed deflection values increased as loads were increased from 300 to 450 N. Opening-closing angles were effective on deflection values. The lowest deflection value was determined for angle “a” and highest deflection value was determined for angle “d”. These results are supported by variance analysis.

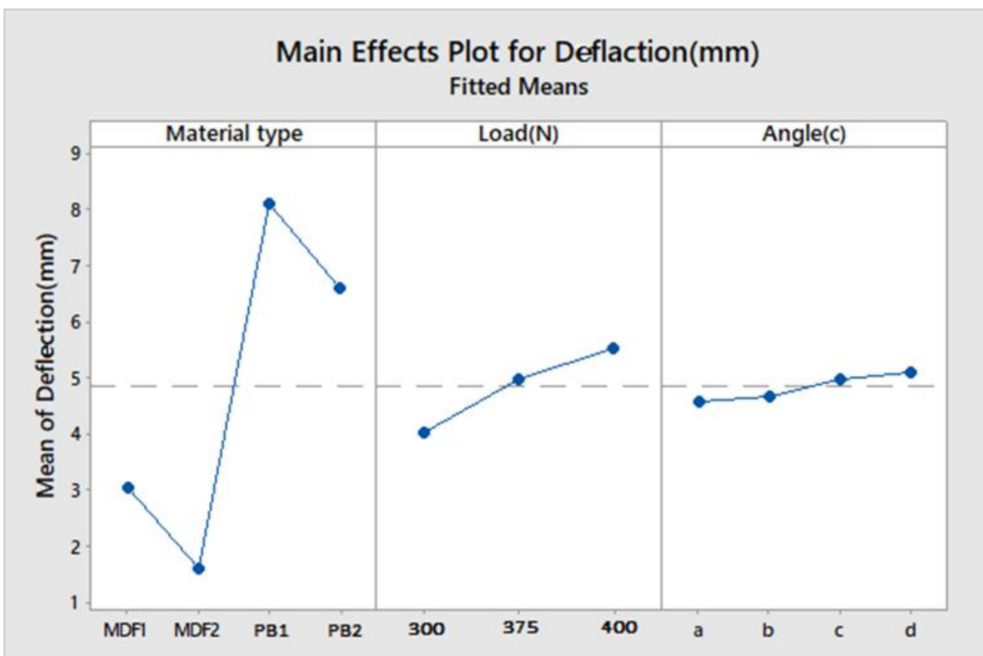

Fig. 8. Main effect plot for mean of deflection

As illustrated in Fig. 9, the interaction between the material type and the load was significant. When MDF 1 and MDF 2 were assessed, the deflection value increased as the load increased. However, the deflection value in MDF 1 was higher than in MDF 2. Furthermore, within the analysis conducted for PB 1 and PB 2, the highest deflection value was found in PB 1 and the least in PB 2.

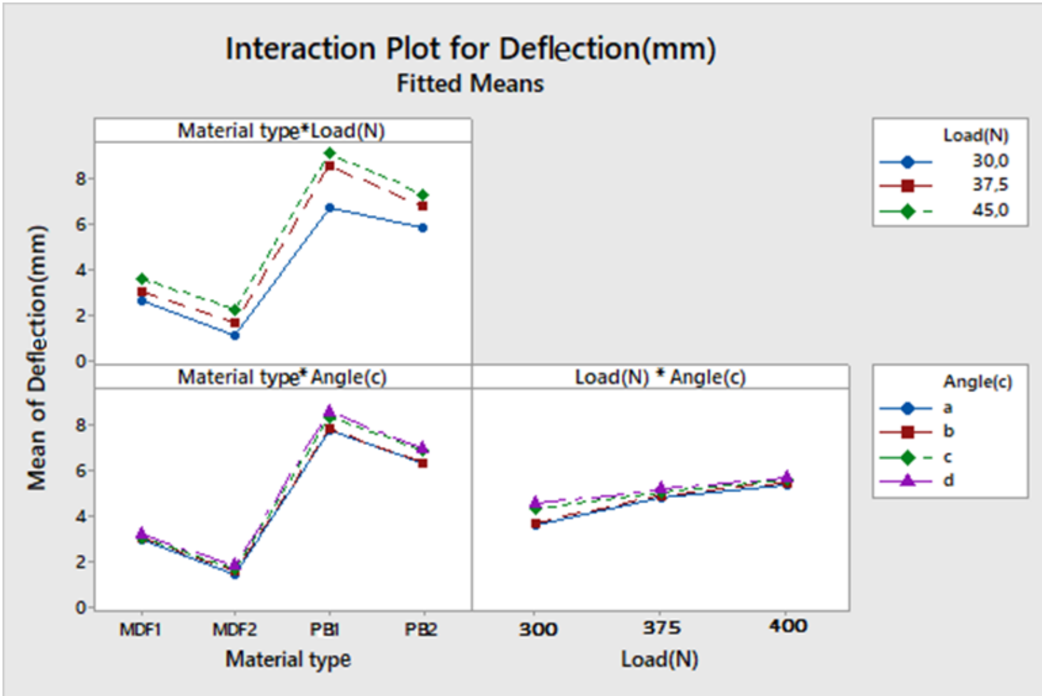

Fig. 9. Interaction plot for material type, angle, and load

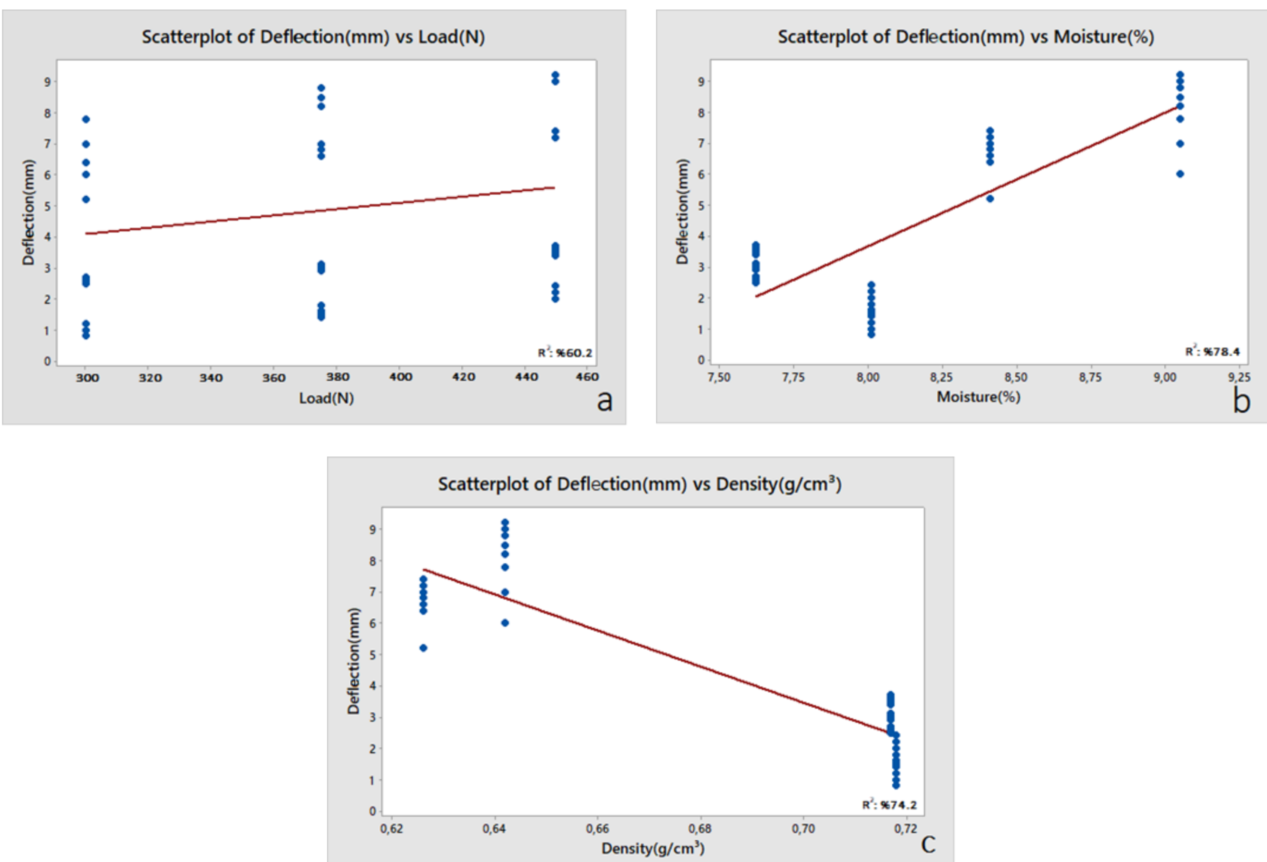

Fig. 10. Deflection Scatter plot for (a) load, (b) moisture, and (c) density

Variance analysis showed that the load force is an important factor and deflection value increases as the load force increases. On the other hand, based on Fig. 10b findings by variance analysis, it was found that the deflection value increased as the moisture content increased. Last, the variance analysis findings of Fig. 10c illustrate that the deflection value decreases as the material density increases.

In the current study, the density values of all four samples were examined, and it was determined that they were directly proportional to the deflection values. Furthermore, it was also determined that the deflection value is inversely proportional to the material's moisture content. Zhou *et al*. (2012) observed that the materials with high modulus of elasticity should be used to improve the dimensional stability of cabinet doors.

In the study, an increase in deflection values under different loads were determined. Smardzewski and Majewski (2013) determined the deflection values of the doors under a load of 300 N and determined that the door not only rotated during loading, but also displaced downwards which supports the results of this study.

According to the experiment results, MDF 1 and MDF 2 displayed higher performance values with comparison to PB 1 and PB 2. Similarly, in his study Sert determined higher performance values for MDF on different hinge configurations for MDF and particleboard (Sert 2018).

CONCLUSIONS

1. Material type, angle, and load variables were determined to be effective on deflection values utilizing variance analysis. At the same time, the interaction between material type and load was found to be significant. Adequacy of models was evaluated with the use of R-square (R^2) and Adjusted R-square (Adj-R^2) values. These values were found to be 88.23% and 86.58%, respectively. Additional conclusions, especially if they deal with more particular issues of the research, would be placed later in the list, though authors may use their own discretion.
2. The deflection value increased when the load increased from 300 to 450 N. The load and opening-closing angle have impact on the deflection value where the lowest deflection value was found at angle "a," while the highest deflection value was found at angle "d".
3. Interaction effect findings: The interaction between the material type and the load was significant. Especially when the PB 2 results were examined, it was seen that the deflection values were close in 375 and 450 N loads.
4. A scatter plot was employed to investigate the relationship of each sample deflection since the used material type had different densities and moisture contents. It was observed that the deflection value decreased as the material density increased, while the deflection value increased as the moisture content increased.
5. While the deflection value of MDF samples with high density decreased, it was increased in particleboard samples with low density.
6. In the study performing three different loads, four different angles, and two materials, the factor determined to be affecting the displacement amount in the doors was angles. The results also include that it caused visible deformations in the hinges during the tests conducted at different angles in the experiments

ACKNOWLEDGMENTS

This study was funded by Scientific Research Projects Coordination Unit of Istanbul University-Cerrahpasa. Project number: “34785”.

REFERENCES CITED

BS EN 322 (1993). “Wood-based panels. Determination of moisture content,” British Standards Institution, London.

BS EN 323 (1993). “Wood-based panels. Determination of density,” British Standards Institution, London.

BS EN 16122 (2012). “Domestic and non-domestic storage furniture — Test methods for the determination of strength, durability and stability. BSI Standards Publication, Test procedures for movable parts, Strength of pivoted doors. Vertical load of pivoted doors,” British Standards Institution, London.

Cai, L., and Wang, F. (1993). “Influence of the stiffness of the corner joint on case furniture deflection,” *Holz Roh Werkst* 51, 406-408.

Efe, H., and Imirzi, H. Ö. (2007). “Mechanical behaviour properties of various fasteners used in furniture production,” *J. Polytech*. 10, 93-103.

Haftkhani, A. R., Ebrahimi, G., Tajvidi, M., Layeghi, M., and Arabi, M. (2011). “Lateral resistance of joints made with various screws in commercial wood plastic composites,” *Materials & Design* 32(7), 4062-4068. DOI: 10.1016/j.matdes.2011.03.020

Hao, J., Xu, L., Wu, X., and Li, X. (2020). “Analysis and modeling of the dowel connection in wood T type joint for optimal performance,” *Composite Structures* 253. DOI: 10.1016/j.compstruct.2020.112754

Kamboj, G., Gaff, M., Smardzewski J., Haviarová, E., Boruvka, V., and Kumar, A. (2020). “Numerical and experimental investigation on the elastic stiffness of glued dovetail joints,” *Construction and Building Materials* 263, article no. 120613, DOI: 10.1016/j.conbuildmat.2020.120613

Kasal, A., Zhang, J., Yüksel, M., and Erdil, Y. Z. (2005). “Effects of screw sizes on load bearing capacity and stiffness of five-sided furni-ture cases constructed of particleboard and medium density fiberboard,” *Forest Prod. J*., 58(10), 25-32.

Kasal, A., Smardzewski, J., Kusgun, T., and Erdil, Y. Z. (2016). “Numerical analyses of various sizes of mortise and tenon furniture joints,” *BioResources* 11(3), 6836-6853. DOI: 10.15376/biores.11.3.6836-6853

Kowaluk, G., Fuczek, D., Beer, P., and Grześkiewicz, M. (2011). “Influence of the raw materials and production parameters on chosen standard properties for furniture panels of bio-composites from fibrous chips,” *BioResources* 6(3), 3004-3018

Kucuktuvek, M., Kasal, A., Kusgun, T., and Erdil, Y.Z. (2017). “Utilizing poppy husk-based particleboards as an alternative material in case furniture construction,” *BioResources* 12, 839-852.

Maleki, S., Kazami, N. S., Ebrahimi, G., and Ghofrani, M. (2017). “Withdrawal resistance of screws in structural composite lumber made of poplar (*Populus deltoides*),” *Construction and Building Materials* 142, 499-505. DOI: 10.1016/j.conbuildmat.2017.03.039

Montgomery, D. C. (1997). *Design and Analysis of Experiment*, Wiley, New York, pp 218-224.

Myers, R. H., Montgomery, D. C., and Anderson-Cook, C. M. (2009). *Process and Product Optimization using Designed Experiments*, Wiley, New Jersey, pp 36-44.

Myers, R. H., Montgomery, D. C., and Anderson-Cook, C. M. (2016). *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, Wiley, New Jersey, pp. 24.

Nicholls, T., and Crisan, R. (2002). "Study of the stress-strain state in corner joints and box type furniture using finite element analysis (FEA)," *Holz Roh Werkst*. 60, 67-71.

Ozcifci, A. (2009). "The effects of pilot hole, screw types and layer thickness on the withdrawal strength of screws in laminated veneer lumber," *Mater Des*. 30(2), 2355-2358.

Ozkaya, K., Burdurlu, E., Ilce, A. C., and Ciritcioglu, H. H. (2010). "Diagonal tensile strength of an oriented strand-board (OSB) frame with dovetail corner joint," *BioResources* 5, 2690-2701.

Prekrat, S., and Spanic, N. (2009). "Scientific methods for determination of wooden corner joint designs," *Drv. Ind*. 60, 245-251.

Saleem, M. M., and Somá, A. (2014). "Design of experiments based factorial design and response surface methodology for MEMS Optimization," *Microsyst. Technol.* 21(1), 263-276. DOI: 10.1007/s00542-014-2186-8

Sert, A. (2018). "Determination of optimum aspect ratio in furniture covers according to sheet type and hinge configuration," Mugla Sıtkı Kocman Institute of Science, Master Thesis.

Smardzewski, J. (2004). "Modeling of semi-rigid joints of the confirmate type," *Ann. Warsaw Agri. Univ. Forest Wood Technol.* 55, 486-490.

Smardzewski, J. (2005). "The reliability of cabinet furniture," *Przemysł Drzewny* (6), 24-27.

Smardzewski, J., and Ozarska, B. (2005). "Rigidity of cabinet furniture with semi-rigid joints of the confirmat type," *Electron. J. Polish Agri. Univ. Wood Technol.* 8(2). <http://www.ejpau.media.pl/articles/volume8/issue2/art-32.pdf>.

Smardzewski, J. (2009). "The reliability of joints and cabinet furniture," *Wood Res*. 54(1), 67-76.

Smardzewski, J., and Majewska, A. (2013). "Strength and durability of furniture drawers and doors," *Materials & Design* 51, 61-66. DOI: 10.1016/j.matdes.2013.03.101

Smardzewski, J., Lewandowski, W., and Imirzi, H. O. (2014). "Elasticity modulus of cabinet furniture joints," *Materials & Design* 60, 260-266. DOI: 10.1016/j.matdes.2014.03.066

Smardzewski, J., Majewski, A., and Łabęda, K. (2014). "Effect of the hinge configuration on the dimensional behavior of furniture doors," *EJPAU* 17(4), 06. http://www.ejpau.media.pl/volume17/issue4/art-06.html

Smardzewski, J. (2015). *Furniture Design*, Springer International Publishing Switzerland, ISBN 978-3-319-19532-2, DOI 10.1007/978-3-319-19533-9.

Smardzewski, J., Imirzi, H. O., Lange, J., and Podskarbi, M. B (2015). "Assessment method of bench joints made of wood-based composites," *Composite Structures* 123, 123-131. DOI: 10.1016/j.compstruct.2014.12.039

Smardzewski, J., Rzepa, B., and Kilic, K. H. (2016). "Mechanical properties of externally invisible furniture joints made of wood-based composites," *BioResources* 11, 1224-1239.

TS 9215 (2005). "Strength and balance tests for furniture," Turkish Committee for Standardization, Ankara, Turkey.

Vassiliou, V., and Barboutis, I. (2005). "Screw withdrawal capacity used in the eccentric joints of cabinet furniture connectors in particleboard and MDF," *J. Wood Sci*. 51, 572-576.

Vassiliou, V., and Barboutis, I. (2009). "Bending strength of furniture corner joints constructed with insert fittings," *Ann. Warsaw Univ. Life Sci. – SGGW For. Wood Technol*. 67, 268-274.

Wang, Y., and Lee, S. H. (2014). "Design and analysis on interference fit in the hardwood dowel-glued joint by finite element method," *Procedia Engineering* 79, 166-172. DOI: 10.1016/j.proeng.2014.06.326

Yuksel, M., Kasal, A., Erdil, Y. Z., Acar, M., and Kusgun, T. (2015). "Effects of the panel and fastener type on bending moment capacity of L-type joints for furniture cases," *Pro Ligno* 11, 426-431.

Zhou, J., Hu, C. H., Hu, S., Yun, H., and Jiang, G. (2012). "Optimization of hinge configuration of furniture doors using finite elements analysis," *BioResources* 7(4), 5809-5816.

Article submitted: June 21, 2022; Peer review completed: October 1, 2022; Revised version received: October 19, 2022; Published: January 3, 2023.
DOI: 10.15376/biores.18.1.1384-1397