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ARTÍCULO

Influences of oak utilization on the medium density fiberboard properties

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Abstract:
Softwoods are the basic and traditional raw materials for medium-density fiberboard production. However, sustainable consumption of wood material in the production of wood-based products requires material variety. Therefore, the usability of hardwood species in the production and its effects on the board properties should be of interest. Considering this, the influence of oak utilization percentages (30 %, 50 %, 70 %, and 100 %) on the physical (density, thickness swelling-TS 2 and 24 h) and mechanical (modulus of rupture, modulus of elasticity, internal bonding, screw holding resistance, and Janka hardness) properties of medium density fiberboard was evaluated in this study. Boards were factory-made instead of laboratory-made using *Quercus petraea* (oak), *Fagus orientalis* (beech), and *Pinus sylvester* (Scots pine) fibers. According to the results, the modulus of rupture, modulus of elasticity, and Janka hardness values were increased when medium-density fiberboard was produced using only oak fiber. On the contrary, thickness swelling, screw-holding resistance, and internal bonding properties were decreased.

Keywords: Medium density fiberboard, modulus of rupture, modulus of elasticity, oak, screw holding resistance, thickness swelling.

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Introduction

One of the commonly used engineered wood-based composite products for construction and building applications, and particularly for the manufacture of furniture, is fiberboard. Fiberboards are often divided into low, medium, and high-density categories based on their density. Medium-density fiberboard (MDF) typically has a density of 600 or 640 kg/m³ to 800 kg/m³ (Levy 2012, Saharudin *et al.* 2020) and has successfully created its niche in numerous utilizations (Arya *et al.* 2023). MDF is conventionally constructed from softwood, but currently, it can be formed from a wide range of components, including wood, trash, recycled paper, bamboo, steel, glass, carbon fibers, polymers, and off-cuts from sawmills and forests (Kubba 2010). Additionally, both virgin and recycled wood or agricultural-based materials can be used in the production of fiberboard which makes the board a sustainable engineered product.

Even though softwood species are the traditionally used material in board production, the utilization of hardwood species in production is of interest for sustainability and property improvement. Therefore, boards can be produced using standalone hardwood species or mixed with softwood species. However, optimizing the production parameters such as fiber mixture is crucial to obtain a well-balanced board for the commercial market. Oak wood is one of the essential hardwood species that is naturally grown in Türkiye. Due to the wide range of utilization abilities either in furniture or wood-based products, the followings are some of the recent studies that tried to figure out different properties of MDF produced using standalone or mixture with oak fiber.

The effect of final board density on thickness swelling-TS (2 h and 24 h), Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bonding (IB) strength, and Janka hardness properties (Akgül *et al.* 2007), roughness properties of commercial MDF (composed of oak, beech, and pine fiber mixture) (Akbulut and Koç 2006), wettability and surface roughness (Akgül *et al.* 2012), effect of calcite on color, water absorption (WA), TS, toluene percentage on the surface, MOE, MOR, IB, screw holding resistance (SHR), Janka hardness of MDF composed of oriental beech (*Fagus orientalis*), oak (*Quercus robur*), and scotch pine (*Pinus sylvestris*) fibers (Çamlıbel and Akgül 2020), influence of zeolite (3 %, 6 %, and 9 % wt.) on density, moisture content (MC), TS, WA, MOR, MOE, IB, and formaldehyde emission (FE) of 14 mm thick MDF produced using

70:30 mixture of hardwood beech (*Fagus orientalis*) and oak (*Quercus robur* L.) and softwood scotch pine (*Pinus sylvestris*), respectively (Camlıbel 2020), comparison of TS, WA, MOR, MOE, IB, SHR properties of MDFs produced using a 30:35:35 fiber mixture of scotch pine (*Pinus sylvestris*), beech (*Fagus orientalis*), and oak (*Quercus robur*), respectively and agri-based biomass added (20 % wt.) boards using okra and tobacco stalks, hazelnut and walnut shell, and pinecone, respectively (Akgül *et al.* 2017), impact of tree species oak (*Quercus robur*), beech (*Fagus orientalis*), and black pine (*Pinus nigra*) and their mixtures (40 %, 40 %, 20 %, respectively) on the MOE, TS, SHR, and Janka hardness (Ayrılmış 2002), evaluation of fungal decay resistance of MDF produced using black pine (*Pinus nigra*), beech (*Fagus orientalis*), and oak (*Quercus robur*) furnishes, and the mixture of these species (20 %, 40 %, and 40 %, respectively) (Kartal and Green 2003), influence of burned pine and unburned beech and oak utilization on the density, MOR, MOE, IB, SHR, TS, Janka hardness, surface roughness, and color properties (Akgül *et al.* 2013), production of eco-friendly MDF using a 57:35:8 mixture of european beech (*Fagus sylvatica*), oak (*Quercus robur*), and silver poplar (*Populus alba*) fibers, respectively (Savov and Antov 2020) and mixture of scotch pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) (Antov *et al.* 2021) fibers for the determination of WA, TS, MOR, MOE, and IB, and influence of hot-pressing parameters on the WA, TS, MOR, MOE, IB of eco-friendly MDF composed of 60:20:20 mixture of European beech (*Fagus sylvatica*), oak (*Quercus cerris*), and silver poplar (*Populus alba*) fibers, respectively (Valchev *et al.* 2021), the effect of modified bonding application on the WA, TS, MOE, MOR, and IB for MDF composed of a 20:20:60 mixture of beech, oak, and pine fibers, respectively (Savov *et al.* 2022) were reported.

It should be taken into consideration that boards used in the studies were generally laboratory-type or commercially obtained. Therefore, a standardized board production may not be achieved which may cause variations in the samples. Furthermore, scarcely any studies dealt with the utilization of sessile oak (*Quercus petraea*) wood (either standalone or blend) in MDF production via actual factory. Moreover, the availability of such materials locally or regionally and the demand for such specific products should be the subject of further research. Then, it would be easier to reveal acceptable substitute materials (Neitzel *et al*. 2022). Therefore, this study aimed to investigate the usability of the oak fibers in standardized MDF production by itself or mixture with one hardwood and one softwood species.

Materials and methods

Material

Oak (*Quercus petraea*), beech (*Fagus orientalis*), and Scots pine (*Pinus syslvester*) were used in this study. Raw wood materials were obtained from Bolu, Zonguldak, and Adapazarı, Türkiye, respectively.

Adhesive

Urea-formaldehyde (UF) resin was used as a binding chemical. The properties of the resin which was produced by Polisan (Gebze, Türkiye) are presented in Table 1.

Table 1: Adhesive properties.

Properties	Value
Solid matter	65±1
UF mole ratio	1,17
Density (gr/cm³ @ 20 ºC)	1,23
Viscosity (cP @ 25°C)	20-35
Gel time (s @ 100°C) (20% $(NH4)_2SO_4$)	20-45
pH	7,5-8,5
Free formaldehyde (Maximum) (%)	0,25
Metilol groups (%)	12-15
Shelf time (Day)	90

Hardener

Ammonium sulfate ($(NH4)_2SO_4$) was used for hardening the UF resin. The chemical was purchased from a private company located in Gebze, Türkiye. The density and pH of the solution (20 % wt.) are 0,98 gr/cm³ and 6,5, respectively.

Paraffin

Off-white liquid paraffin was purchased from Mercan Kimya Company (Denizli, Türkiye). The solid matter, pH, and density properties of the paraffin are 60 %, 9-11, and 0,98 gr/cm³, respectively.

Board production

Boards were produced in Divapan Entegre Plant, Düzce, Türkiye. As seen in Table 2, four different board types were manufactured in terms of oak utilization percentages. Each wood species was separately chipped, stored, and fed to production as presented percentages by the discharge screw. An oscillating screen was used for chip screening. Pre-steaming was performed using 140 ºC temperature and 2,7 bar steam pressure in the chip bin to ensure precise and balanced chip discharge and uniform moisture. Before the defibrillation process, liquid paraffin was applied to the chip mixtures by the discharge screw. Chips were cooked for around 3 min at 185 ºC temperature and 7,8 bar steam pressure. Asplund defibrillator refiner and Andritz defibrillator (Andritz AG, Graz, Austria) were used in these phases. Chemicals were applied and then fibers were dried till their moisture reached 12 %. Homogenous and uniform mats were coldly pre-pressed using 110 kg/cm² - 90 kg/cm² - 105 kg/cm² pressures. The 1860 mm x 3690 mm rough-sized mats were hot pressed using a multi-layer (8) press. As seen in Table 2, pressing parameters were fixed for all groups.

MDF boards were cooled to room temperature using a star-type cooler, sized in the cutting unit, and stored for 5 days. The board surfaces were sequentially sanded using 40, 80, and 120 sand abrasive papers. Eventually, 18 mm x 1830 mm x 3660 mm boards were produced. As seen in Figure 1, boards were stored in flat floor storage without any natural or engineered airflow.

Table 2: MDF production parameters.

	Type 1 ($O^*_{30}S^{**}_{30}B^{***}_{40}$)	Type 2 ($O_{50}S_{25}B_{25}$)	Type 3 ($O_{70}S_{15}B_{15}$)	Type 4 (O_{100})
Wood Mixture (%)	30+30+40	50+25+25	70+15+15	100
UF (kg/m^3)	58	58	58	58
Liquid paraffin (kg/m^3)	1,15	1,15	1,15	1,15
Hardener (kg/m^3)	0,75	0,75	0,75	0,75
Press time (s)	275	275	275	275
Pressure (kp/cm^2)	32	32	32	32
Press temperature (ºC)	188	188	188	188
Press speed (mm/s)	145	145	145	145
Board size (mm)	18x1830x3660	18 x 1830 x 3660	18 x 1830 x 3660	18 x 1830 x 3660

* oak, ** Scots pine, *** beech

Figure 1: (a) Production line and (b) stored MDFs.

Measurements

In accordance with the related standards, total of 640 samples (20 replicates for each property) were prepared and acclimatized at 65±5 % relative humidity and 20±2 ºC temperature and then tested using IB 200 test machine (Figure 2) (IMAL Srl, San Damaso, Italy). The physical properties (TS EN 622-5 2006), swelling in thickness after immersion in water for 2h and 24 h (TS EN 317 1999), density (TS EN 323 1999), MOE in bending and MOR (TS EN 310 1999), IB perpendicular to the plane (TS EN 319 1999), Janka hardness (ASTM D-1037-78 1994), and axial withdrawal of screws (BS EN 320 2011) were determined.

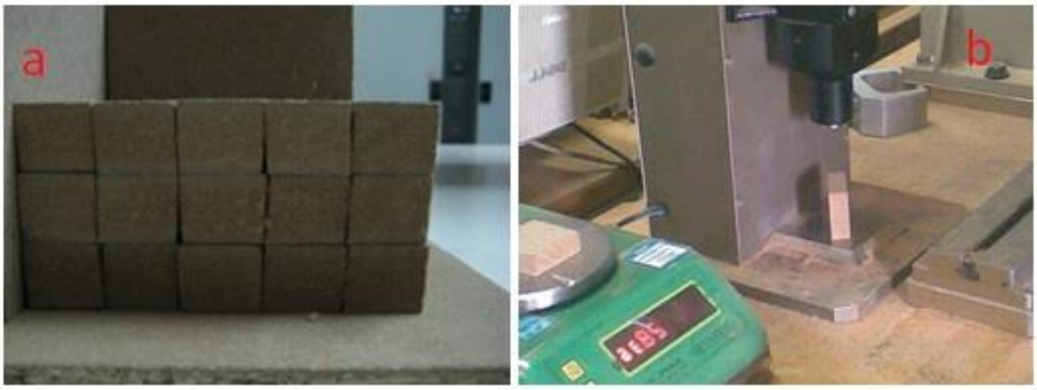

Figure 2: (a) Samples and (b) laboratory testing machine.

One-way analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) were performed to figure out the statistically significant differences. The confidence interval was 95 % for the statistics.

Results and discussion

Average values and statistics for the physical properties are presented in Table 3. The MC of the boards are around 12 %. As seen in the table, density averages ranged from 715 kg/m^3 to 754 kg/m^3 and decreased when the oak percentage in the fiber mixture was increased. The reported average densities for the MDF produced using standalone oak (*Quercus robur*) fiber or mixture with beech and pine fibers ranged from 707 kg/m^3 (Akgül *et al.* 2017) to 763 kg/m^3 (Ayrılmış 2002). According to Gul *et al.* (2017) typical MDF density ranges from 690 kg/m^3 to 750 kg/m^3. When the differences between oak species are ignored, the density of the 15 mm thick MDF produced using the same fiber combination was reported as 713 kg/m^3 (Çamlıbel and Yılmaz Aydın 2020), and there is around a 5,5 % difference which is reasonable. Therefore, the board densities are in accordance with the standards and literature.

The uniform density profile across the thickness of the board is presented in Figure 3, and as Xie *et al.* (2011) expressed, repeatedly fluctuating density across the thickness partially demonstrates the cross-linked layered structure of fiber dispersion across the thickness.

According to DMRT results seen in Table 3, there are statistically significant differences ($P<0,05$) between the density means. Around a 5,2 % decrease in density was seen when the boards were produced using only oak fiber. Apart from the production parameters, wood species is an essential determinant of the board density, and defining the right species with the optimum amount is crucial, particularly for lightweight MDF production. Because, in general, wood species have densities higher than 300 kg/m^3 (Xie *et al.* 2011). Therefore, using low-density wood species or mixing the species is one of the ways to reduce the final density other than arranging the production parameters. In this study, a different mixture of oak, beech, and Scots pine woods were utilized. The reported densities for Scots pine (*Pinus sylvestris*), sessile oak (*Quercus petraea*), and beech (*Fagus orientalis*) are 500 kg/m^3 (Özan *et al.* 2017), 690 kg/m^3 (Yılmaz Aydın and Aydın 2020), and 680 kg/m^3 (Yılmaz Aydın and Aydın 2018), respectively.

As seen in Table 3, the 2 h immersion in water provided 1,5 % to 3,8 % swelling percentages while 24 h caused higher swelling percentages that ranged from 7,75 % to 10,6 %. Furthermore, the means presented statistically significant differences. As in density variations, boards produced using only oak fiber presented the highest swelling percentages. Contrary, boards with the lowest oak share (30 %) provided the lowest TS. The same is true for the 2 h immersion process however there were no statistically significant differences between $O_{50}S_{25}B_{25}$ and $O_{70}S_{15}B_{15}$, and $O_{70}S_{15}B_{15}$ and O_{100}. Furthermore, TS 2 h and 24 h of O_{100} boards were around 2,5 and 1,4 times higher than $O_{30}S_{30}B_{40}$ boards. Therefore, $O_{30}S_{30}B_{40}$ composition for the board production can be chosen when TS performance is taken into consideration. When reported TS percentages, 3,81 % for 2 h (Çamlıbel and Akgül 2020), and 9,5 % (Akgül *et al*. 2013) to 28,81 % (Çamlıbel 2020) for 24 h, are taken into consideration for the boards produced using mixed oak fiber, results of this study are fair enough.

Table 3: Statistics for physical properties.

Properties	Groups	N	Mean[DHG]	Std. Dev.	Std. Error	95 % CI* for Mean		Min.	Max.
						Lower	Upper		
Density (kg/m^3)	$O_{30}S_{30}B_{40}$	20	754[d]	11,30	2,53	748,89	759,46	738	782
	$O_{50}S_{25}B_{25}$	20	734[c]	10,88	2,43	728,61	738,80	712	753
	$O_{70}S_{15}B_{15}$	20	724[b]	19,16	4,28	715,36	733,30	684	753
	O_{100}	20	716[a]	3,54	0,79	714,12	717,44	709	723
TS 2 h (%)	$O_{30}S_{30}B_{40}$	20	1,55[a]	0,10	0,02	1,50	1,59	1,33	1,67
	$O_{50}S_{25}B_{25}$	20	3,46[b]	0,37	0,08	3,28	3,63	2,86	4,36
	$O_{70}S_{15}B_{15}$	20	3,61[bc]	0,48	0,11	3,38	3,84	2,86	4,36
	O_{100}	20	3,83[c]	0,42	0,09	3,63	4,03	3,31	4,62
TS 24 h (%)	$O_{30}S_{30}B_{40}$	20	7,76[a]	0,86	0,19	7,35	8,16	6,02	9
	$O_{50}S_{25}B_{25}$	20	8,64[b]	0,77	0,17	8,28	9	7,11	9,96
	$O_{70}S_{15}B_{15}$	20	9,22[c]	0,72	0,16	8,88	9,56	7,55	10,04
	O_{100}	20	10,60[d]	0,25	0,06	10,49	10,72	10,18	11,04

[DHG] Duncan's homogeneity groups ([a-d]), and *Confidence Intervals

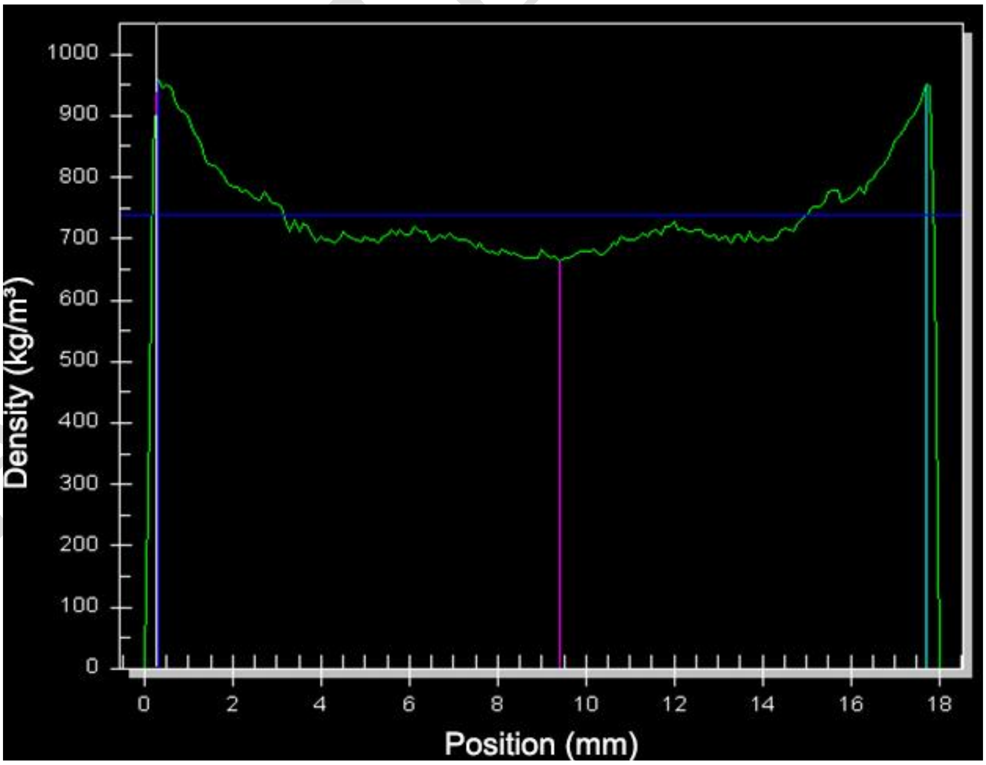

Figure 3: Density profile of the boards.

The means and statistics for the mechanical properties are presented in Table 4. Both MOR and MOE in bending were increased with the increase in oak fiber percentage. Furthermore, values reached their maximum when boards were produced using only oak fiber. Around 28,9 % and 31,1 % increases were observed in MOR and MOE in bending values. According to DMRT, only $O_{30}S_{30}B_{40}$ board presented statistically significant differences for MOR, and there were no statistically significant differences between $O_{50}S_{25}B_{25}$ and $O_{70}S_{15}B_{15}$ for MOE in bending. When considering MOR and MOE improvements, boards should be produced using oak wood instead of blending these tree species. However, the lowest IB strength was obtained when the boards were produced without any mixture. Additionally, the highest IB strength was obtained when the board composition was $O_{50}S_{25}B_{25}$. However, as seen in the table, there was only a 7,9 % difference between the highest and lowest values. There were insignificant statistical differences between the means of boards that were produced using a mixture of soft and hardwoods. Furthermore, the IB strengths of the boards composed of the blended chips did not present stable increases or decreases. As seen in Table 5, the results of this study conform to the reported MOR, MOE, and IB values ranging from 21,97 MPa to 36,89 MPa, 2628 MPa to 4248 MPa, and 0,49 MPa to 0,66 MPa, respectively.

The SHR of the boards produced with the mixtures were close to each other. On the other hand, the mean of the boards produced using 100 % oak fiber presented around 20,57 % lower performance than the averages of the mixed boards. Furthermore, such a remarkable difference caused a statistically significant difference ($P<0,05$) while other means did not. Other than the board properties such as material, production parameters, etc., orientation and major diameter of the screw, pilot hole, and soaking types are some of the factors that have significant influences on the SHR (Yorur *et al.* 2020). Due to these factors, values greatly vary as seen in Table 5 and as Yüksel *et al.* (2022) reported; 233,5 N to 3186,3 N.

The Janka hardness values were increased with the increase of oak proportion. Around a 4,11 % increase in hardness was obtained when the board was produced using 100 % oak fiber. However, there was only a 1,53 % increase when the 30 % oak share in the blend increased to 70 %. Therefore, standalone oak fiber might be preferred to produce boards. The hardness values are comparable with the literature seen in Table 5. Ayrılmış (2002) reported that using black pine (*Pinus nigra*) furnish instead of oak (*Quercus robur*), and beech (*Fagus orientalis*) or a mixture of them provides better mechanical properties except Janka hardness. However, in this study, using standalone oak fiber provided a higher and significantly different mean.

Table 4: Statistics for mechanical properties.

Properties	Groups	N	Mean[DHG]	Std. Dev.	Std. Error	95 % CI* for Mean		Min.	Max.
						Lower	Upper		
MOR (MPa)	$O_{30}S_{30}B_{40}$	20	27,86[a]	1,94	0,43	26,96	28,77	24,93	30,31
	$O_{50}S_{25}B_{25}$	20	34,46[b]	2,22	0,50	33,42	35,50	31,16	39,85
	$O_{70}S_{15}B_{15}$	20	34,73[b]	2,45	0,55	33,59	35,89	31,16	39,85
	O_{100}	20	35,90[b]	2,40	0,54	34,78	37,02	32,57	39,66
MOE (MPa)	$O_{30}S_{30}B_{40}$	20	2631,50[a]	178,84	39,99	2547,80	2715,21	2271,18	2915,92
	$O_{50}S_{25}B_{25}$	20	3158,41[b]	166,81	37,30	3080,35	3236,48	2751,75	3382,77
	$O_{70}S_{15}B_{15}$	20	3162,10[b]	169,76	37,96	3082,65	3241,55	2751,80	3382,80
	O_{100}	20	3448,93[c]	205,42	45,93	3352,79	3545,08	3091,80	3754,10
IB (MPa)	$O_{30}S_{30}B_{40}$	20	0,62[b]	0,06	0,01	0,60	0,65	0,55	0,72
	$O_{50}S_{25}B_{25}$	20	0,63[b]	0,05	0,01	0,61	0,66	0,56	0,73
	$O_{70}S_{15}B_{15}$	20	0,62[b]	0,04	0,01	0,61	0,64	0,56	0,70
	O_{100}	20	0,58[a]	0,03	0,01	0,57	0,60	0,54	0,63
SHR (MPa)	$O_{30}S_{30}B_{40}$	20	126,95[b]	7,07	1,58	123,64	130,26	115	136
	$O_{50}S_{25}B_{25}$	20	126,75[b]	7,15	1,60	123,40	130,10	115	136
	$O_{70}S_{15}B_{15}$	20	125,60[b]	6,77	1,51	122,43	128,77	115	136
	O_{100}	20	100,42[a]	2,79	0,62	99,11	101,72	97,70	105,7
Janka Hardness (MPa)	$O_{30}S_{30}B_{40}$	20	77,85[a]	1,73	0,39	77,04	78,66	75	81
	$O_{50}S_{25}B_{25}$	20	78,69[ab]	0,96	0,21	78,24	79,14	76,70	80
	$O_{70}S_{15}B_{15}$	20	79,04[b]	1,47	0,33	78,35	79,73	76,70	82
	O_{100}	20	81,05[c]	1,23	0,28	80,47	81,63	79	83

[DHG] Duncan's homogeneity groups ([a-c]), and *Confidence Intervals

Table 5: Comparative data for MDF produced using different fiber compositions.

Ref.	Fiber composition (100 %)	Density (kg/m^3)	MC (%)	Thickness (mm)	TS 2 h (%)	TS 24 h (%)	MOR (MPa)	MOE (MPa)	IB (MPa)	SHR (N)	Janka (MPa)
(Çamlıbel and Yılmaz Aydın 2020)	70 % (FO and QR) 30 % (PS)	713	4,2	14,6		27,36					
(Camlibel 2020)	70 % (FO and QR) 30 % (PS)	743	4,2	14		28,81	31,92	3384	0,66		
(Camlibel and Akgul 2020)	70 % (FO and QR) 30 % (PS)	715	12	18	3.81	10,55	36,89	3483	0,58	10,07	81,05 (N)
(Akgül *et al.* 2017)	35 % FO, 35 % QR, and30% PN	707	12	18		25,76	21,97	4248	0,49	1117	
(Ayrılmış 2002)	QR (100)	763		18			27,04	2858		927	55,51
(Ayrılmış 2002)	40 % FO, 40 % QR, and 20 % PN			18			30,8	2952		962	53,51
(Akgül *et al.* 2013)	50 % QR and 50 % FO	754	12	18		9,5	27,9	2628	0,62	1163	7790 (N)

FO; *Fagus orientalis*, QR; *Quercus robur*, PS; *Pinus sylvestris*and PN; *Pinus nigra*.

As can be seen in Table 6, except for SHR, there are significant numerical differences between interior and exterior values. When considering these requirements, MDF produced using oak fiber does not meet the IB requirement for outdoor utilization. However, both physical and mechanical properties (except IB) are significantly higher than interior values. Furthermore, except for TS 24 h and IB for P7 type boards (heavy duty-humid condition), all the produced MDFs met all the requirements of the TS EN 312 (2005) standard. When higher MOR, MOE, and Janka hardness properties are required, oak fiber comes to the forefront.

Table 6: MDF property requirements (Density 640 kg/m^3 to 800 kg/m^3) (Levy 2012).

Utilization	Nominal thickness(mm)	MOR (MPa)	MOE (MPa)	IB (MPa)	SHR Face (N)	SHR Edge (N)
Interior	≤ 21	24	2400	0,6	1,445	1,110
Exterior	≤ 21	34,5	3450	0,9	1,445	1,110

Mean physical and mechanical values and error bars for graphical expression or comparison of the data variations are presented in Figures 4-7. Also, a scatterplot matrix, seen in Figure 8, presents all the pair-wise scatter plots of evaluated variables for the MDF production.

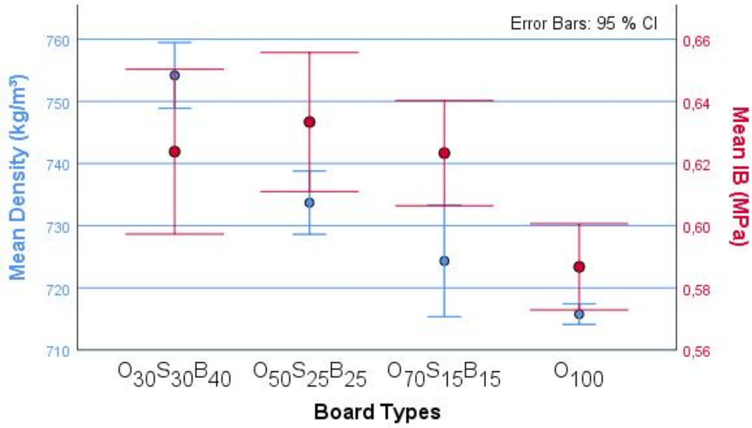

Figure 4: Means and error bars for density and internal bonding.

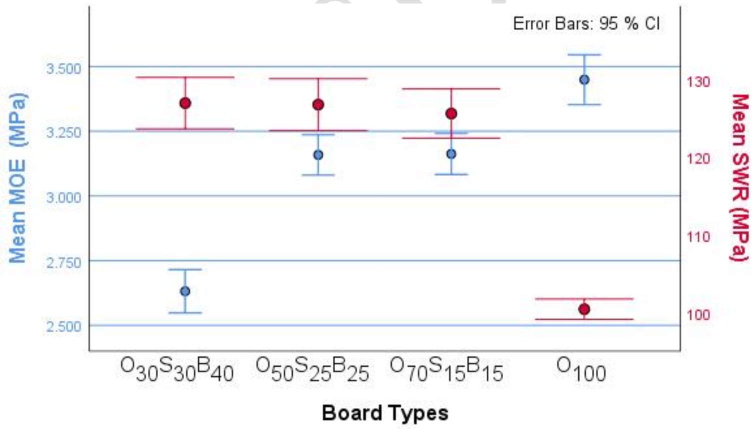

Figure 5: Means and error bars for MOE and SHR.

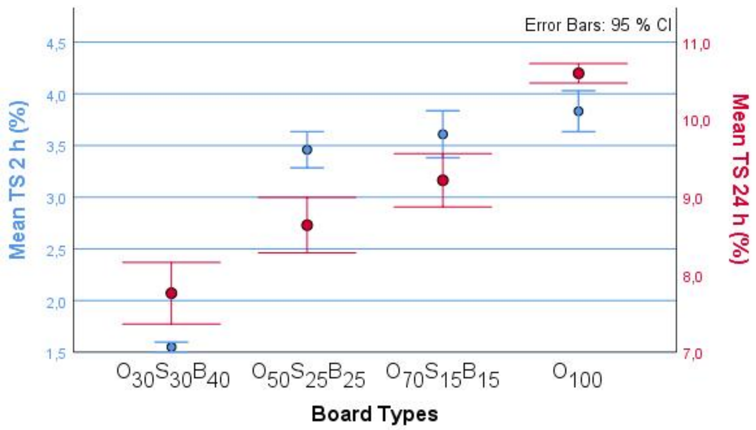

Figure 6: Means and error bars for TS 2 h and 24 h.

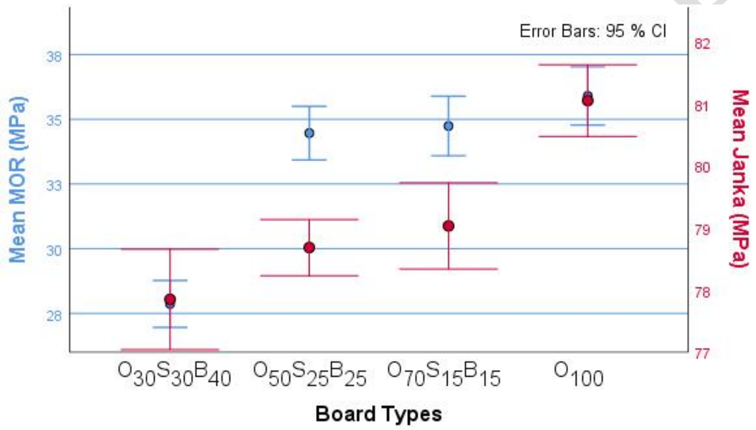

Figure 7: Means and error bars for MOR and Janka hardness.

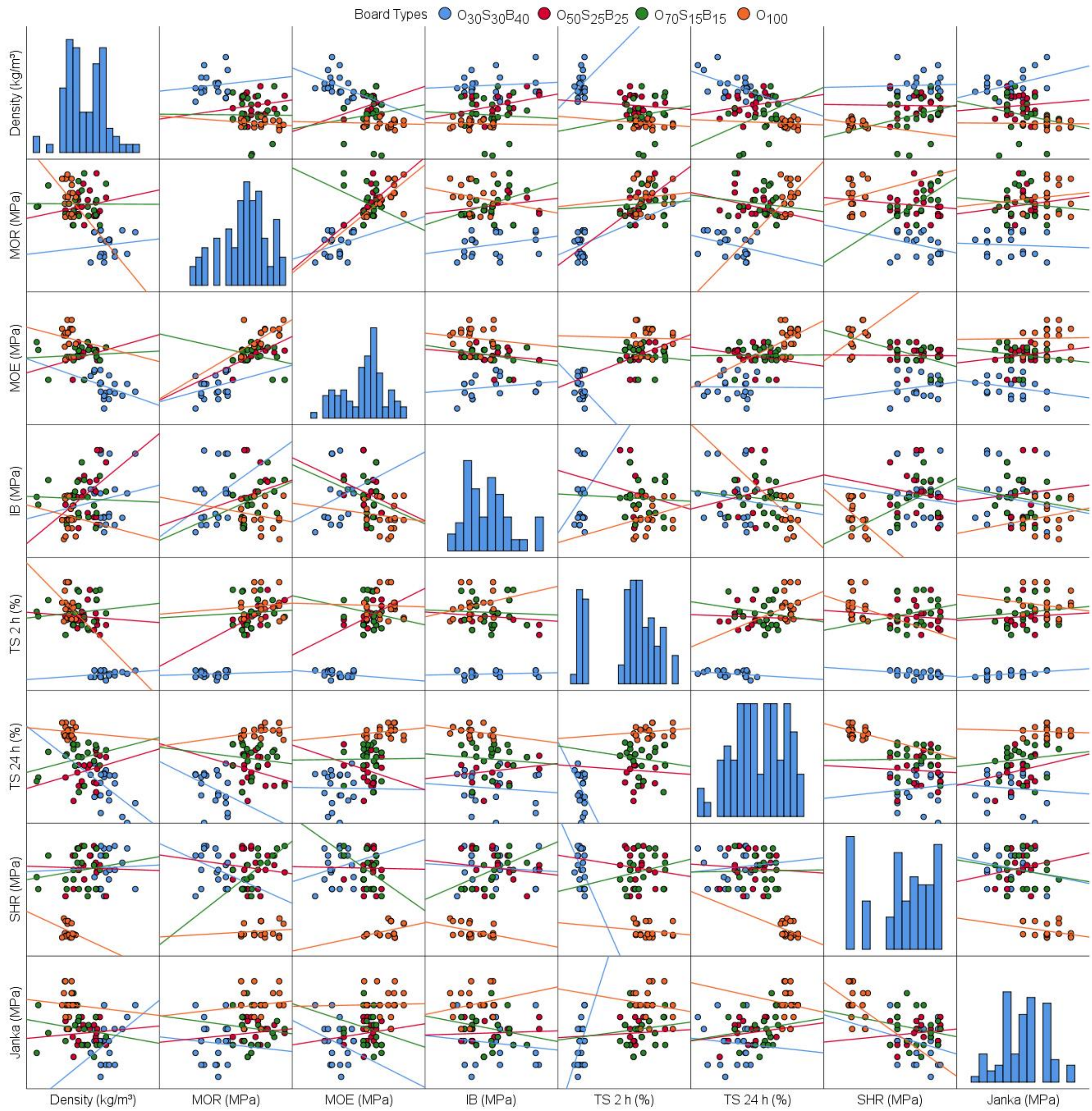

Figure 8: Scatterplot matrix for the physical and mechanical properties.

Conclusions

In this study effect of oak utilization percentages on the physical and mechanical properties of MDF was evaluated. In general, statistically significant differences in the means were observed. When higher MOR, MOE, and Janka hardness values are desired, boards might be produced using only oak fiber instead of blending with beech and Scots pine. It should be taken into consideration that the highest values correspond to the lowest density boards produced using only oak fiber. Swelling in thickness was increased when the proportion of oak in the fiber mixture was increased. Therefore, to provide a better swelling performance, the proportion of oak in the fiber mixture should be less. The IB strength was the only property that fluctuated with the increase in oak percentage in the fiber mixture. However, this fluctuation was scarcely any and statistically insignificant within the boards produced using the blended fibers.

Diversification of the wood material in MDF production is important for sustainable consumption of the raw materials, particularly for the conifers even if they are renewable. Therefore, oak can be a suitable choice for MDF production due to its ability to meet the standard requirements either standalone or blended with other species.

Authorship contributions

O. Ç.: Conceptualization, data curation; formal analysis; investigation; methodology; resources; writing-original draft. M. A.: Formal analysis; writing-original draft; visualization; writing-review & editing. E. K.: Investigation; writing-original draft.

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