WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.5.837846
e-ISSN 2729-8906
67(5): 2022 837-846 pp.

INFLUENCE OF PUMICE POWDER ON SOME PROPERTIES OF PHENOL-FORMALDEHYDE BONDED PARTICLEBOARDS

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(RECEIVED FEBRUARY 2022)

ABSTRACT

In this study, pumice powder as a volcanic aggregate was added in the particleboards' production. The effect of various ratios of pumice powder (10%, 20%, 30%, and 40%) on physical, mechanical, thermal and fire resistance properties was investigated. Pumice powder did not significantly affect particleboards' water absorption and thickness swelling values. However, the mechanical properties were significantly affected with raising pumice powder content. The modulus of rupture and modulus of elasticity decreased up to 46% and 45%, respectively. There was also a decrease in the internal bond strength up to 42%. Conversely, pumice powder improved the thermal degradation temperatures. The onset temperatures increased with increasing pumice powder content above 300°C. Similarly, the pumice powder improved the fire resistance of particleboards up to 7% compared to control samples.

KEYWORDS: Pumice powder, thermogravimetric analysis, LOI test, physico-mechanical properties.

INTRODUCTION

Today, it has become necessary to use composites in various products because of rising costs, competition, and raw material shortage (Kim et al. 2019). In this aspect, the interest in wood-based composites such as particleboard, fiberboard, plywood, etc., has increased in the industry. They are used for furniture, building parts, and various products for accommodations (Wang 2013). The market share of particleboard has recently risen worldwide due to being a homogenous material. Moreover, the low production cost attracts the attention of manufacturers (Ovodunni et al. 2020). However, it also has undesirable properties such as formaldehyde emission, water absorption, flammability, low strength, and low biological resistance (Ovodunni et al. 2020, Sellers 2000, Nourbakhsh 2010).

In Turkey, approximately 70% of the raw wood material used in wood-based panels has been supplied from Canada, Russia, and Ukraine due to insufficient resources in recent decades (Ayrılmış et al. 2009). The rising market share of wood-based composites has caused the need to look for alternative materials to wood due to limited forest resources. There are many studies about the usability of lignocellulosic biomass, rice husks, pruning stalks, hemp fibers, and similar lignocellulosic wastes in producing wood-based composites (Akgül et al. 2017, Battegazzore et al. 2018, Lau et al. 2021, Yeniocak et al. 2020).

Moreover, mineral-based resources have also tried to be evaluated in the production (Yang and Li 2019, Cavdar 2020). Pumice is a popular volcanic stone with essential properties such as high surface area and mechanical stability, which is evaluated in the construction industry due to its cheapness and abundance (Motlagh et al. 2021). It is a volcanic-based alumina-silica, which is mainly composed of SiO_2. Dissolved gases precipitate during the cooling when the lava throws via the air, which causes it to have a porous structure. It has low thermal conductivity and density because of its porous structure. The degradation at high temperatures and high chemical resistance make it the most preferred material in the industry (Sellers 2000, Nazohic et al. 2012).

The combustion properties of wood-based materials are an important parameter for determining the usage area (Park et al. 2014). Light aggregates such as pumice, slag, and expanded clay showed excellent fire performance and low thermal conductivity in themselves (Shoabib et al. 2001). Therefore, they have an important potential to improve the fire resistance of wood-based composites.

The main objective of this study was to examine the usability of pumice powder in particleboard production. The effect of pumice powder on the physical, mechanical, thermal properties, and fire resistance was investigated. The density and dimensional stability of particleboards were determined as physical properties. The modulus of rupture, modulus of elasticity, and internal bond strength were also examined as mechanical properties. Moreover, the degradation with increasing temperature was also investigated by thermogravimetric analysis (TGA). The fire resistance was determined by the limit oxygen index test.

MATERIALS AND METHODS

Materials

In this study, poplar wood (*Populus Alba* L.) was used as a raw material for production of particleboard. Firstly, the stem wood were chipped by using a Vecoplan hacker to obtain coarse particles. Then R. Hildebrand knife ring flaker was used to get smaller particles. Wood flakes were sieved using a four-stage Algemaier brand circular motion sieve to obtain wood particles, whose dimensions are between 3 mm - 1.5 mm for the core and 1.5 - 0.5 mm for the surface layer. Phenol formaldehyde (PF), with a solid content of 50%, was used in the manufacturing process as resin. PF adhesive content were 9% and 11% of the dried weight of surface layer and core wood particles, respectively. The design of the study was given in Tab. 1.

Tab. 1: The design of the study.

Board types	Wood particle (%)	Pumice powder (%)
C	100	0
P10	90	10
P20	80	20
P30	70	30
P40	60	40

Preparation of particleboard

The boards were produced in three layers, and the gluing was carried out with a laboratory-type automatic gluing machine. The shelling ratio (face : core) was 40 : 60 (%). The target density was 650 $kg \cdot cm^{-3}$. The draft (550 x 550 x 10 mm^3) was formed as hand-made and pressed in hot press with a 24 $kg \cdot cm^{-2}$ pressure at 150ºC for 7 min. Duplicate particleboards were prepared for each group. The structure of particleboards is also seen in Fig. 1.

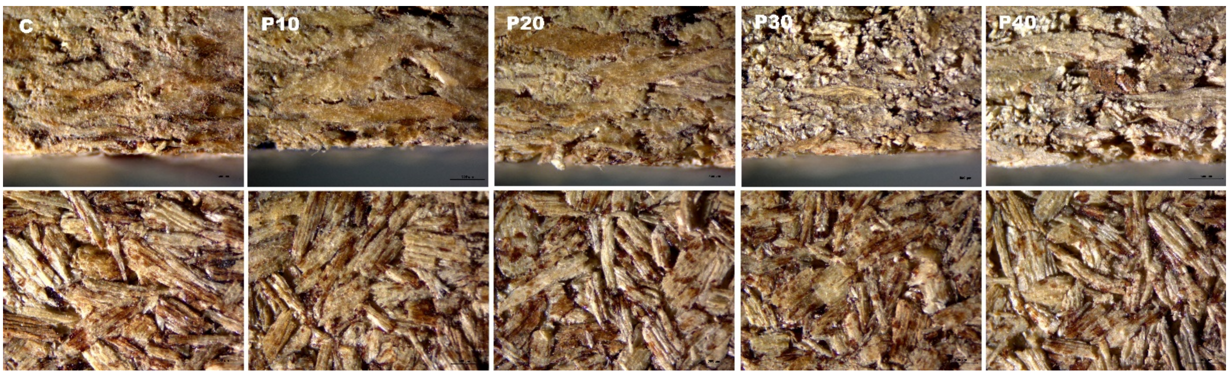

Fig. 1: Light microscopy images of particleboards.

Physical properties

Density, water absorption (WA), and thickness swelling (TS) were determined according to EN 323: 1993; EN 317: 1993; ASTM-D1037-12: 2020. The results were interpreted according to EN 312: 2010 standard.

Mechanical properties

Modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB) properties of the boards were determined according to EN 310: 1993; EN 319: 1993. The results were interpreted according to EN 312: 2010.

Thermogravimetric analysis (TGA/DTG)

Thermogravimetric analysis (TGA) was performed using the PerkinElmer TGA-6000 thermogravimetric analyzer (USA). Analysis was carried out from 35°C to 900°C at a heating rate of $10°C \cdot min^{-1}$.

The limit oxygen index test (LOI)

The limited oxygen index (LOI) test was carried out using the Dynisco LOI chamber (Franklin, USA) according to the ASTM D2863-19: 2006 standard. The dimensions of samples were $100 \times 15 \times 10\ mm^3$. Four samples from each group were tested for the LOI test.

Statistical analysis

All the analyzes were statically investigated (SPSS, IBM Corporation, Version 23, USA). The data were statistically analyzed according to the analysis of variance (ANOVA). The difference between the groups was also determined by the Duncan test ($p < 0.05$).

RESULTS AND DISCUSSION

Physical and mechanical properties

The effect of pumice powder on particleboards' physical and mechanical properties was investigated, as seen in Tab. 2. Density is an essential parameter that directly affects the properties of materials. In the beginning, the density increased with decreasing wood content up to 30% pumice powder. The highest density values were obtained in the 20% and 30% pumice powder particleboards. After that, a decrease was observed. The viscoelastic behavior of wood fiber causes the decreased density of boards. While the pumice powder content increased, wood content decreases. Therefore, the panels having high wood content tend to increase in thickness. As a result of this, the decrease in density was inevitable.

The TS and WA values after 24 h varied from 16.56% to 17.74% and 66.26% to 77.32%, respectively. However, these values did not meet the requirement of EN 312: 2010. TS values were higher than the EN standard (15%). While adding pumice powder in the production did not significantly influence the TS values, it does affect WA values ($p < 0.05$). WA values increased with increasing pumice powder content, except 30%. The porous structure of pumice can cause it to absorb more water (Rashad, 2019). The amount of WA and TS increases with increasing minerals content due to their hydrophilic properties in the board (Özdemir 2019). Moreover, Camlibel and Akgul (2020) determined that WA and TS values increased with 3%, 6%, and 9% calcite addition in MDF production.

The pumice powder influenced the mechanical properties of particleboard negatively. The increment in the pumice powder content decreased the mechanical properties. The decrease reached up to 46% and 45% for MOR and MOE, respectively. Control samples provided the top values, while P40 was the lowest. Meanwhile, pumice powder up to 20% met the requirements of EN standards, which was above 12.5 MPa. EN standard restricted the addition of pumice powder up to 20%. Above this content did not meet 1800 MPa, which is the requirement furniture manufacturing of (EN 312-5: 2012). Likewise, IB values decreased up to 42% with increasing pumice powder content. The lowest IB value was found from P40, while the highest was control samples. Although the decrease in IB values, all groups met the requirements of EN standards (0.40 MPa). However, there were also differences between the groups statically. The reduction in the contact point and adhesion strength between the component in the particleboard with increasing pumice content could decrease mechanical properties. Moreover, the addition of inorganic additives changes the curing behavior of the adhesive, which reduces the resistance values (Ozyhar 2020). The addition of pumice powder could also decrease the bonding capacity between the wood fiber and adhesive (Ayrılmış et al. 2017).

Tab. 2: Physical and mechanical properties of particleboards.

Board properties	Number of samples	Board type	Mean	Standard deviation	Standard error	X min	X max	P
Density ($g\cdot cm^{-3}$)	15	C	0.661^{AB}	0.056	0.01	0.59	0.76	**
		P10	0.640^{C}	0.029	0.01	0.61	0.70	
		P20	0.692^{A}	0.040	0.01	0.62	0.75	
		P30	0.680^{A}	0.043	0.01	0.62	0.74	
		P40	0.664^{AB}	0.045	0.01	0.60	0.75	
WA (%)	15	C	70.34^{A}	7.93	2.05	58.80	81.42	***
		P10	66.26^{A}	7.43	1.92	57.44	82.58	
		P20	75.27^{B}	4.48	1.16	69.92	83.79	
		P30	69.91^{A}	4.96	1.28	61.69	77.34	
		P40	77.32^{B}	5.18	1.34	66.75	84.11	
TS (%)	15	C	16.54^{A}	1.68	0.43	14.00	19.86	ns
		P10	16.56^{A}	1.77	0.46	14.21	20.36	
		P20	17.74^{A}	1.44	0.37	15.21	20.01	
		P30	17.19^{A}	1.56	0.40	14.51	19.77	
		P40	17.58^{A}	1.49	0.38	15.08	20.85	
MOR (MPa)	15	C	14.72^{A}	1.39	0.36	12.30	17.10	***
		P10	13.95^{A}	1.71	0.44	10.38	16.65	
		P20	12.71^{B}	0.97	0.25	11.33	14.84	
		P30	10.28^{C}	1.69	0.44	8.08	13.34	
		P40	7.90^{D}	1.04	0.27	6.52	10.99	
MOE (MPa)	15	C	2285^{A}	229	59.06	1985	2672	***
		P10	2032^{B}	196	50.66	1718	2388	
		P20	1970^{B}	203	52.38	1728	2374	
		P30	1671^{C}	224	57.77	1301	2097	
		P40	1248^{D}	177	45.70	1126	1815	
IB (MPa)	15	C	0.71^{A}	0.09	0.02	0.61	0.93	***
		P10	0.65^{A}	0.08	0.02	0.44	0.79	
		P20	0.62^{B}	0.10	0.03	0.40	0.82	
		P30	0.54^{C}	0.08	0.02	0.38	0.75	
		P40	0.41^{D}	0.06	0.02	0.28	0.57	

Note: Letters (A,B,C,D) indicate homogeneity groups. Different letters indicate different homogeneity groups, $p < 0.05$; ns- not significant; **-significant on $\alpha = 1\%$; ***- significant on $\alpha = 0.05\%$.

Thermogravimetric analysis (TGA/DTG)

The effect of pumice powder on the thermal degradation with gradual temperature increase was investigated (Fig. 2). The degradation temperatures and char residue values are also given in Tab. 3. The first stage, which started around 100°C and finished at 200°C, demonstrated the absorbed water content of samples. In this stage, all samples lost approximately 8% of weight loss. After that, the degradation of wood cell wall components starts. However, the beginning temperature of the pyrolysis reaction is different for wood cell wall components. The decomposition of hemicelluloses, celluloses, and lignin occurs at temperatures between 200-380°C, 250-380°C, and 180°C, respectively. However, the oxidation of charred wood residue takes place above 450°C (Gašparovič et al. 2010, Dietenberger and Hasburgh 2016).

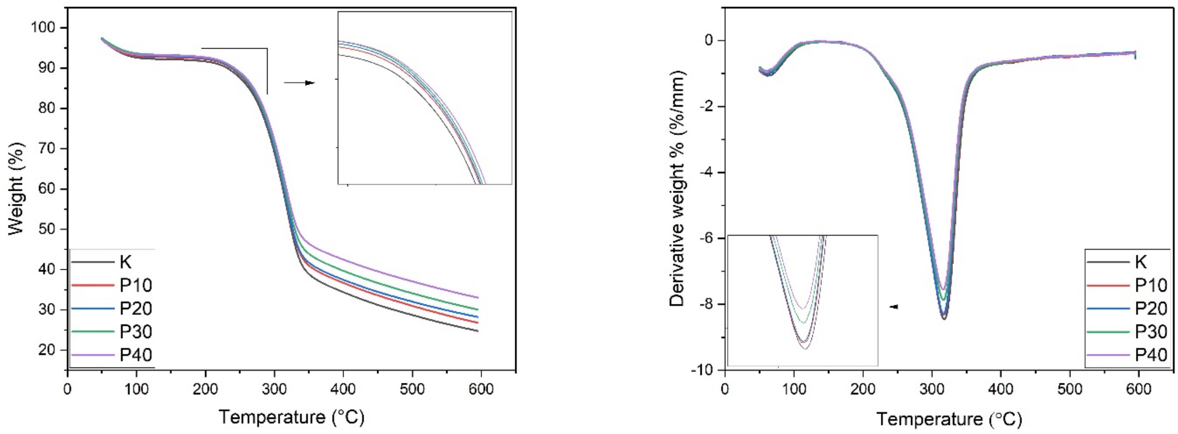

Fig. 2: Thermogravimetric analysis of particleboards.

The onset temperature (T_{on}) varied between 282-303°C. The addition of pumice powder increased the initial decomposition temperature compared to control samples. Similarly, the maximum degradation temperature (T_{max}) showed that decomposition was retarded with pumice powder. However, P40 was slightly below the control samples. The char residue at 595°C increased with increasing pumice powder content. Pumice is a thermally resistant material, and its weight loss at 800°C is 5% (Turan et al. 2014). Therefore, the material's thermal stability increases with the addition of pumice powder. Likewise, adding pumice powder into wood polymer composites increases thermal stability (Koyuncu 2018) .

Tab. 3: Calculated results from TGA and DTG curves of particleboards.

Board types	T_{on} (°C)^A	T_{end} (°C)^B	T_{max} (°C)^C	Char residue (%)		
				200°C	400°C	590°C
C	282.70	334.98	317.86	91.65	34.38	24.94
P10	303.80	303.80	326.97	92.23	36.69	26.99
P20	282.74	329.59	308.92	92.46	37.46	28.39
P30	291.64	332.72	325.40	92.64	39.77	30.25
P40	279.44	333.40	317.67	92.67	42.47	33.22

Limit oxygen index test

The LOI value determines the minimum oxygen requirement for a material to combustion. The higher the value, the more difficult it is for the material to burn. According to the LOI results, the addition of pumice powder positively affected the fire resistance of the boards, as seen in Fig. 3. While the LOI value of the control group was 32.6%, it was 35% for P40. The pumice powder improved LOI values up to 7% compared to control samples. The pumice powder provides fire resistance to materials due to its volcanic rock structure (El Gamal and Hashem 2017). Since aggregates such as pumice are exposed to high temperatures during formation, they have a high resistance to high-temperature degradation (Turker et al. 2001). As stated above, the amount of char residue increased with pumice powder. The char residue has a fire retardant effect by preventing the entry of oxygen into the material and heat transfer (Gayathri et al. 2015). Therefore, it can be said that the burning of the particleboards becomes more difficult.

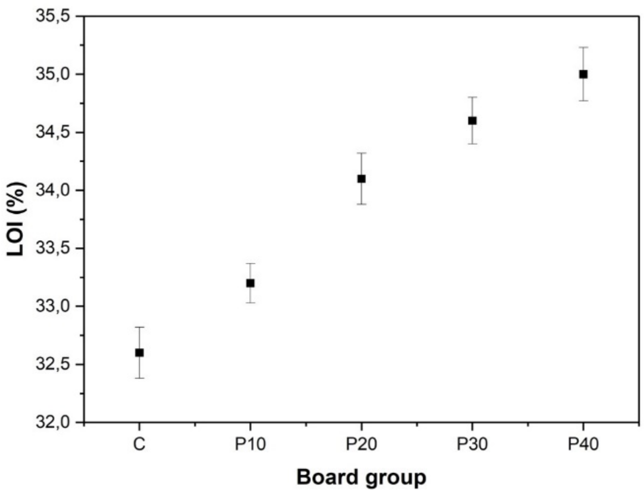

Fig. 4: LOI analysis of particleboards.

CONCLUSIONS

The influence of pumice powder on the properties of phenol-formaldehyde particleboards was examined in this study. According to obtained results, the addition of pumice powder neither made a significant change in the TS nor WA. However, the reduction in the mechanical properties was significant. The decrease in the adhesion between wood fiber and resin with the effect of pumice powder negatively affected mechanical properties. The decrease reached up to 46% and 45% for MOR and MOE, respectively. Similarly, there was also a reduction in the IB values, which reached 42%. However, the use of 10% pumice powder did not significantly change the MOR and IB values, while the increase in the amount of pumice powder decreased the mechanical properties. On the other hand, pumice powder positively influenced the thermal properties of particleboards. The onset temperature was increased with increasing pumice powder above 300°C. Likewise, the need for oxygen increased for flaming combustion. The addition of pumice powder improved the flame retardancy of particleboards up to 7%. It could be stated that the pumice powder with low content could be added to the particleboard productions, which almost did not considerably influence the mechanical properties but improved the thermal properties considerably.

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