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Influences of some factors on the formaldehyde content of particleboard

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Abstract

In this study, effects of specific gravity (SG), shelling ratio, wood species, and pressure on the formaldehyde content, physical (SG and thickness swelling (TS)), and mechanical properties (modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) strength) of particleboard were examined. The best manufacturing parameters were determined for E_1 grade particleboard manufacturing from urea formaldehyde (UF) adhesive. Based on the findings of this study, increasing of SG, shelling ratio, and pressure increased the formaldehyde content. Particleboard made from particles consisting higher amount of beech particles had lower formaldehyde content than that of panel from particles consisting higher amount of pine particles.

Keywords: Particleboard; Urea formaldehyde; E_1 grade; Formaldehyde content

1. Introduction

Particleboard is a wood panel product used widely in the manufacture of furniture, floor underlayment, home constructions, cabinets, stair treads, shelving, table tops, vanities, speakers, sliding doors, lock blocks, interior signs, displays, table tennis, pool tables, electronic game consoles, paneling, kitchen worktops, and work surfaces in offices, educational establishments, laboratories, and other industrial product applications [1].

Formaldehyde is one of the world's most ubiquitous chemicals. It is a simple chemical compound made of carbon, hydrogen, and oxygen (CHOH), which are produced naturally by plants, animals, and humans as part of the normal life process. It provides an important source of single carbon molecules in the production of polymer adhesives used in the manufacture of particleboards. More than 90% of particleboards are bonded with urea formaldehyde (UF) resins as they provide strong, durable bonds and at low cost. Over the past several decades, air pollution in homes and office buildings has become a matter of increasing concern. Formaldehyde emission has been the major concern associated with bonded wood products. [2–5].

Because of its reactivity, toxicity, and pungent odor, formaldehyde has been regulated in the work place for many years in many countries. In 1980, Swenberg et al. published the results their study at the Chemical Institute of Industrial Toxicology using rats and mice showing that high levels of formaldehyde induced nasal cancers in rats. Formaldehyde was found to be a substance that may cause cancer and irreversible health effects. With the first oil crisis in 1972 and the ensuing pressure to improve insulation and reduce ventilation in buildings, problems of formaldehyde odor in buildings began to arise and works carried out focused on two main subjects: What are the factors affecting the formaldehyde release and how to reduce the formaldehyde emission. Guidelines on the use of particleboards in building were produced and the E_1, and E_2 terms were introduced [6–8].

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This study aimed to determine the effects of some factors on the E_1 grade particleboard manufacturing. While the effects of specific gravity (SG), pressure, shelling ratio, and wood species on the formaldehyde emission were determined, the changes on the physical and mechanical properties related to these factors were investigated. The properties of panels determined were mechanical properties (modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB)), physical properties (SG and thickness swelling (TS)), and formaldehyde content (FC).

2. Material and methods

Wood particles consist of beech (*Fagus orientalis* Lipsky.), pine (*Pinus nigra* Arn. subst. *Pallasiana* (Lanb.) Holmboe.), and poplar (*Populus tremula* L.) and were obtained from a commercial particleboard plant in Turkey and dried to 1% moisture content before use. Dried particles were classified into two-size categories, namely fine and coarse. Fine particles were used for the face layers of the three-layer particleboard while the coarse particles were used for the core layer of the board. Particles were blended with UF resin with a solid content of 60%. Formaldehyde/urea mole ratio of the resin was 1.12. Based on oven dry particle weight, 9% and 11% UF resin were applied for the core and face layers, respectively. Ammonium chloride with a solid content of 20%, and paraffin with a solid content of 32% were used for the panel manufacture. The mats (280 by 210 by 1.8 cm thick) were formed and pressed under $3.5\,N/mm^2$ pressure, at 225 °C for 110 s. All panels were sanded using a sequence of 40, 60, and 80 grits. After sanding, particleboards were conditioned at a temperature of 20 °C and 65% relative humidity. A total of 30 experimental panels, 3 for each type of furnish, were made. Table 1 displays the experimental design of this study.

Thirty samples from each panel were prepared for modulus of rupture, modulus of elasticity, IB strength, and TS tests based on EN specifications and they were conditioned at a temperature of 20 °C and 65% relative humidity before any tests were carried out [9–11]. To determine the FC, perforator method was employed which is listed in the standard EN 120 [8]. Three samples were used for this test. FC was determined after a week from particleboard manufacture. The perforator method is a procedure for the extraction with toluene of small particleboard samples. The extracted formaldehyde is sampled in water and determined by the iodine method. The FC is expressed in milligrams of formaldehyde per 100 g of dry board.

Data for each test were statistically analyzed. Analysis of variance (ANOVA) was used to test for significant difference between factors and levels. When the ANOVA indicated a significant difference among factors and levels, a comparison of the means was done employing a Newman–Keuls test to identify.

Table 1
The experimental design

Panel type	Target specific gravity (g/cm^3)	Pressure (kg/cm^2)	Shelling ratio[a] (%)
A	0.60	30	32
B	0.70	30	32
C	0.60	35	32
D	0.70	35	32
E	0.60	30	45
F	0.70	30	45
G	0.60	35	45
H	0.70	35	45
I[b]	0.70	30	32
J[b]	0.60	35	32

[a]The shelling ratio is the ratio of the face thickness to the total thickness of the panels.
[b]Wood particles used for the particleboard manufacturing consist of approximately 70% pine, 20% beech, and 10% poplar. Other board types consist of approximately 70% beech, 20% pine, and 10% poplar particles.

3. Results and discussion

Average values of modulus of rupture, modulus of elasticity, IB strength, SG, TS, and FC are shown in Tables 2 and 3.

Based on EN standards, 11.5, 13.0, and $1600\,N/mm^2$ are the minimum requirements for modulus of rupture modulus of elasticity of particleboard panels for general uses and furniture manufacturing, respectively [12,13]. All of the panels made in this study satisfied the modulus of rupture requirements for general uses with the exception of panels A and C. In addition, D, F, H, and I type panels met the minimum modulus of rupture and modulus of elasticity requirements of the EN standards for furniture manufacturing application. On the other hand, with the exception of panels A and C, all panels were found to comply with IB strength values for general uses which is $0.24\,N/mm^2$ as stated in EN 312-2 (1996) standard. This study showed that panels F, H, and I had the required level of strength for interior fitments (including furniture) i. e., $0.35\,N/mm^2$ according to the EN 312-3 (1996).

Based on standards, particleboard should have a maximum TS value of 8% (for 2 h immersion) for general uses. Average TS of the specimens ranged from 5.03% to 11.79%. According to the test results, D, F, G, H, and I type panels satisfied the TS requirement for general uses.

The average FC of particleboard is lower than 8 mg per 100 g board dry weight, for the emission classes E_1

Table 2
Summary of the test results of the specimens

Type	SG (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	FC* (mg CH_20)
A	0.572 (0.003)	10.42 (0.11)	1045.16 (15.33)	0.188 (0.11)	6.43 (0.10)
B	0.685 (0.006)	12.88 (0.14)	1534.08 (12.74)	0.325 (0.13)	8.16 (0.07)
C	0.594 (0.004)	11.15 (0.09)	1156.27 (20.18)	0.229 (0.08)	7.24 (0.09)
D	0.709 (0.007)	13.24 (0.12)	1643.28 (17.33)	0.343 (0.10)	8.32 (0.05)
E	0.602 (0.005)	11.73 (0.15)	1277.45 (10.86)	0.292 (0.07)	7.48 (0.08)
F	0.713 (0.004)	13.58 (0.10)	1704.34 (13.24)	0.360 (0.16)	8.67 (0.10)
G	0.615 (0.006)	12.41 (0.09)	1300.49 (15.12)	0.281 (0.14)	7.65 (0.06)
H	0.725 (0.003)	13.98 (0.08)	1945.63 (14.02)	0.428 (0.15)	9.24 (0.09)
I	0.716 (0.005)	13.75 (0.13)	1812.36 (11.07)	0.406 (0.09)	8.85 (0.04)
J	0.630 (0.008)	12.59 (0.11)	1445.32 (10.29)	0.307 (0.12)	7.56 (0.06)

Table 3
The thickness swelling values of the specimens

Type	TS (%) 2 h immersion	TS (%) 24 h immersion	TS (%) 48 h immersion	TS (%) 72 h immersion
A	11.79 (0.24)	17.54 (0.08)	24.32 (0.25)	35.42 (0.28)
B	9.48 (0.18)	19.91 (0.10)	25.48 (0.18)	35.49 (0.30)
C	9.53 (0.20)	16.42 (0.09)	24.04 (0.16)	35.37 (0.24)
D	7.36 (0.12)	18.87 (0.07)	25.38 (0.12)	35.43 (0.18)
E	8.24 (0.10)	15.61 (0.12)	23.17 (0.17)	35.26 (0.21)
F	6.01 (0.15)	17.73 (0.06)	24.29 (0.21)	35.38 (0.19)
G	7.12 (0.17)	14.56 (0.08)	23.08 (0.19)	35.18 (0.16)
H	5.03 (0.19)	16.55 (0.05)	24.20 (0.22)	35.31 (0.23)
I	7.45 (0.11)	17.13 (0.12)	23.18 (0.20)	30.12 (0.25)
J	7.50 (0.13)	14.39 (0.07)	21.23 (0.14)	29.04 (0.15)

grade boards. While A, C, E, G, and J type panels were E_1 grade, the other boards were found as E_2 type particleboards based on EN 120-1 (1994) standard. The results showed that G and J type boards also met the required physical and mechanical properties as stated in the relevant standards [12,13].

Increasing of pressure from 30 to 35 kg/cm^2 increased the SG, significantly ($p<0.01$). A similar effect of pressure on the SG was also reported in previous studies [3,14]. Particleboards produced with 45% shelling ratio had higher SG values than those of the panels with 32% shelling ratio ($p<0.01$). Face layers consist of finer particles than core layer. Finer particles could easily get more compressed during the pressing [15].

The manufactured particleboards made from particles consisting 70% pine, 20% beech, and 10% poplar showed significantly higher specific values than panels from 70% beech, 20% pine, and 10% poplar wood particles. This result could be related to the fact that pinewood has lower SG than beech. In the equal pressing conditions, particleboards consist of more amount of pine particles which could get more compressed than panels consisting more amount of beech particles [16].

Performing a statistical analysis of the results, SG, shelling ratio, pressure, and raw material type were found to be effective on the mechanical properties of particleboard. Increasing of SG from 0.60 to 0.70 g/cm^3 improved the modulus of rupture, modulus of elasticity, and IB strength ($p<0.01$). The positive influence of board SG on the mechanical properties was mentioned in a similar work [17]. Particleboards pressed under 35 kg/cm^2 pressure had higher MOR, MOE, and IB strength values than those of panels pressed under 30 kg/cm^2 pressure. This expected finding is due to more compression related to the pressure [3]. Increasing of pine particles amount in the particleboard manufacturing improved the mechanical properties. Particles made from softwoods are smoother, longer, and thinner than hardwood particles. For these reasons, these particles can be blended and pressed successfully. In addition, particles from softwoods do not absorb more amount of the adhesive. There is enough amount of adhesive on the particle surfaces [18,19]. When the shelling ratio was increased to 45%, both IB and bending properties substantially increased. This may be explained by the fact that higher amounts of fine particle usage on the surface layers cause an even tighter structure on the particleboard. Tighter structure on the particleboard surface increases the heat transfer to the core. In addition, more adhesive amount is used in the surface layers than in the core. When the shelling ratio is increased, adhesive usage on the surfaces are more. The positive influence of shelling ratio on the mechanical properties of particleboard was stated in previous works [15,19].

Statistical significant differences were found between the TSs of the samples from various combinations of raw material types, SGs, pressures, and shelling ratios. Increasing of pine particle amount in the particleboard decreased TS for 2, 24, 48, and 72 h immersions, significantly. There are two main reasons explaining these differences: The first one is that some extractives and resin in the pine wood [20] and the second one is the greater compression in the particleboard consisting high amount of pine particles due to lower SG of pine wood than that of beech wood [16]. Related to the second one, more compression ratio can cause low porosity on the board surface and limit the water diffusion.

Particleboards produced with 45% shelling ratio had lower TS values for 2, 24, and 48 h immersions than those of panels with 32% shelling ratio. This expected finding is due to increase of fine particle amount in the board. Fine particles absorb less amount of water than thick particles [3]. No statistically significant difference was found between TS values for 72 h immersion of two shelling ratio parameters. This may be explained by the increase of water diffusion to the board related to the increase of immersion time. Urea resins are not resistant to the water because of their amino methylene linkages. They undergo decomposition with the effect of water absorption of particles [21,22].

Pressure was found to be effective on the TS of panels for 2 and 24 h. immersions, significantly. No significant differences were determined between TS values for 48 and 72 h immersions of the particleboards manufactured under two different pressures. It has been reported that increasing pressure reduced the TS of the panels [15,20].

Increasing of board SG from 0.60 to 0.70 g/cm^3 improved the TS for 2 h immersion, significantly. This may be explained by the fact that low porosity on the board surface due to high SG and difficult water diffusion to the board related to the compact structure. Particleboards at 0.70 g/cm^3 SG had significantly higher TSs than those of board at 0.60 g/cm^3 for 24 and 48 h immersions. This high values may be related to the fact that UF adhesive's resistance to water vapor (hydrolysis) is less [21]. In addition, high amount wood material usage for particleboard manufacturing at 0.70 g/cm^3 causes this result. Based on the statistical analysis, the SG of the panels was not found to be effective on TS for 72 h immersion. This is due to decomposition of the amino methylene linkage of the UF adhesive related to the increasing on the immersion time.

Pressure had a significant influence on the FC. Particleboards manufactured under 30 kg/cm^2 pressure showed lower emission levels than panels manufactured under 35 kg/cm^2. If high pressure is used in the particleboards manufacturing, it is reasonable to suppose that, the more compact and even tighter structure, the lower formaldehyde release from the boards during pressing and one week since their manufacture up to the beginning of the test period. Then the panels manufactured under high pressure had higher FC due to their porous structures [23].

Increasing of shelling ratio from 32% to 45% caused significantly higher FC in particleboard. Fine particles can be compressed easily during the hot pressing. For this reason, higher shelling ratio causes more compact and tighter structures. Formaldehyde is released at higher amounts and easily from particleboards produced at lower shelling ratio during hot pressing and storage. As a result of more amount of formaldehyde release, these boards consist lower formaldehyde during the test [26]. In addition, UF adhesive was used at the level of 11% of the oven dry weight of particles in the face layers during manufacturing. Related to this, increasing of face layer particle usage ratio caused more amount of adhesive applying. Increase of adhesive amount related to the increase of shelling ratio cause more formaldehyde release during the tests [24].

Particleboards at 060 g/cm^3 SG had lower FC than that of panels at 0.70 g/cm^3, significantly. Boards at higher specific gravities have tighter and more compact structure. This gives higher formaldehyde values for these boards in perforator test due to low formaldehyde release during the hot pressing. In addition, adhesive usage amount is related to the particle amount. Increase of SG causes more adhesive usage amount for particleboard production.

Based on statistical analysis, raw material type affected the FC of the particleboard. Increasing of pine particles amount on the board caused higher formaldehyde emission values. When beech particles are used for particleboard manufacturing, it is reasonable to suppose that the bigger the vessel surface, the higher the formaldehyde release from the respective boards during hot pressing and one week since their manufacture upto the beginning of the test. For this reason, boards consisting higher amount of beech particles had lower FC [23]. The second reason explaining the effect of wood species on the formaldehyde emission of particleboard is acetyl groups in the wood. During the hot pressing, acetyl groups release from the wood and acetic acid is formed. This acid is a formaldehyde scavenger. Beech wood consists of more acetic acid than pine. A similar effect of wood species on the formaldehyde emission was also reported in previous studies [25–28].

4. Conclusion

This study showed that specific gravity, pressure, shelling ratio and wood species had a great influence on the physical, mechanical properties, and formaldehyde content of particleboard. Increasing of specific gravity, pressure, and shelling ratio improved the modulus of rupture, modulus of elasticity, and internal bond strength.

However, these factors caused higher formaldehyde contents. Wood species affected all of properties of particleboard. Panels made from particles consisting higher amount of pine particles showed highest formaldehyde content and mechanical properties, and the lowest thickness swelling values. According to the results, it was found that effect of specific gravity on the thickness swelling was related to the immersion time in the water.

For the manufacturing of E_1 grade particleboard, adhesive with low formaldehyde/urea mole ratio usage is not enough. All of the process parameters should be taken into account together. Particleboards should meet the required physical and mechanical properties as stated in the relevant standards and also they must have low formaldehyde content for indoor applications.

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