Formaldehyde Emission in Different Positions of Wood-Based Boards Used in Interior Architecture

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Abstract

This research focuses on determining the effects on the formaldehyde emission (FE) of the middle and edge parts of two different wood-based boards (WBBs) consisting of medium density fiberboard (MDF) and particleboard (PB), which are widely used in interior architecture. Samples with the thicknesses of 18 mm were analyzed for FE at a temperature of 20 °C and 65% relative moisture content for 1, 2 and 3 hours after manufacture. In the PB samples, the highest value of FE (0.4119 ppm) was determined in the samples obtained from the center while the lowest emission value (0.0875) was observed in the samples obtained from the edge. In the MDF samples, the highest value of FE (0.3012 ppm) was determined in the samples from the center while the lowest emission value (0.1807 ppm) was observed in the samples from the edge. The PBs have a higher environmental impact (0.2497 ppm) than the MDFs (0.2454 ppm). For distances to minimum values (0.10 ppm), while the furthest value for the central samples of PB was 311%, the closest value for the edge samples of PB was -12.5%.

Keywords: Formaldehyde Emission, Furniture, Interior Architecture, VOC, Wood-Based Boards.

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INTRODUCTION

Interiors play a significant role in people's lives (Klepeis et al., 2000). For this reason, interior air quality is very important for people's right to live a healthy life. The World Health Organization (WHO, 2014) reports that every year, approximately 4.3 million people die as a result of internal pollutants. As argued by Zhuge et al. (2018) and Landrigan et al. (2018). The global burden of illness is significantly increased recently, Bad interior air quality can be partly attributed to organic chemicals from wood-based boards (WBBs) (Zhangcan et al., 2019). In recent years, as Çınar (2018) states, the intense demand from the construction and furniture industries has seriously affected the consumption of wood materials in the manufacture of WBBs, which are widely used in the furniture industries. The reduction of many natural resources due to global industrialization has become the driving force for product differentiation in the wood industry. Therefore, wood-based materials are widely used and preferred in the production of fixed or movable interior equipment, in the construction industry, and in repair and restoration work. In addition, increasing environmental concerns in recent years, such as public intense, pressure and tougher regulations have altered the way business is conducted. The resulting environmental pressures have a direct impact on the preferences of consumers who are aware of the growing need for sustainable furniture. Wood products industry has begun to improve the properties of products in terms of environmental processes in order to reduce negative public awareness about timber production and management. Moreover, wood-based boards (WBBs) are highly preferred in furniture production and various interior design projects due to their easy processing and dimensional stabilization properties (Zhang et al., 2018).

The rising awareness has led consumers, entrepreneurs and decision-makers to improve their sustainable environmental requirements. This situation impresses the forest products and furniture industries, including the manufacturing and environmental aspects of WBBs (Çınar et al., 2018). WBBs such as medium density fiberboard (MDF), plywood (HWPW) and particleboard (PB) are widely used in interior reinforcement elements and thin construction elements. Their usage time is also quite long (Shalbafan et al., 2016; Trianoski et al., 2017; Latorraca et al., 2009; Salthammer et al., 2010 and Tang et al., 2009). As a result, the manufacture method and stages of WBBs have become a very important issue in terms of being compatible with the environment wood based materials and products. In some studies, it is stated that organic chemicals such as phenolic compounds, organochlorins and formaldehyde (F) emitted from these products cause serious health problems on employees/users (Pearson, 1994; Yıldırım 2013; Cinar and Erdoğdu, 2018). In recent years, many scientific studies have been carried out on formaldehyde emission (FE) and gases emitted from wood-based panels. Free Formaldehydes (Fs) remaining in WBBs are the main source of interior pollution (Zhang et al., 2018). In particular, significant quantities of synthetic adhesives such as phenol (P) or urea formaldehyde (UF) are required for the production of boards. Synthetic adhesives are predominately used in the production of WBBs such as MDF, PB, plywood, and wet-process MDF. UF resin is one of the most preferred synthetic adhesives due to its high performance and low cost, which is widely used in the production of WBBs (Tang et al., 2009; Park and Kim, 2008). The biggest disadvantage of the most popular and widely used UF resin is that it contains FE.

F is defined as a distinctive, colourless, gaseous and flammable substance that exists in various forms at room temperature (Pearson, 1994). The accumulated effect of the concentration of F emitted from the interior equipment and various products can pose a serious danger to the health of people in a closed space. F concentrations among 0.1 ppm and 0.5 ppm can cause redness and burning in the nose, eyes and throat, and some sensitive people can detect this irritation by smell (Salem and Böhm, 2013). Pearson (1994) states that FE produces irritation to the nose, eyes, skin and throat. Given the problems encountered, it often appears to be related to nosebleeds and breathing difficulties and is suspected to be carcinogenic at levels of 0.5 to 1.0 ppm. It can also cause dermatitis as a result of an allergic reaction to organic chemicals on contact (Isaksson et al., 1999). According to Schafer and Roffael (2000), F in wood varies depending on the quality of the wood and the inner layers of the pre-processing. In fact, F concentration is usually very low. Still, the actual release of F comes from the wood adhesives used during and after the production of WBBs. Several case studies on the production, environmental properties and applications of finishes of WBBs have been conducted (Rivela et al., 2006, 2007; Raffael, 2006; Wilson, 2010; González-García et al., 2009; Benotto et al., 2009; Antov et al., 2021; Silva et al., 2013, 2014; Kouchaki-Penchah et al., 2016; Saravia-Cortez et al., 2013; Nakano et al., 2018). Also, some studies focused on the environmental properties of WBBs and the investigation of various varnishes used (USEPA 1998, 2001; Brockmann et al., 1998; Kim and Kim, 2005; Cinar, 2005; Gonzalez et al., 2011; Zhongkai et al., 2012; Chuck and Jeong, 2012; Khanjanzadeh et al., 2014; Aghakhani et al., 2013). Some other studies focused on the effects of the temperature and humidity on FE (H'ng et al., 2012; Luo et al., 2005; Oliveira et al., 2017; Funk et al., 2017, Akkuş et al., 2021). The study of Cinar et al. (2018) shows that there is a strong relationship between increasing FE and increasing thickness and temperature. Furthermore, panel-processing (edge banding, covering panel surfaces, and drilling holes for hinges or handles) has a significant impact on FE (Cinar et al., 2018).

When evaluating WBBs, the literature discussed above provides a useful background on the importance of considering board manufacture, material selection, and regional characteristics. The revelation of the environmental effects of WBBs through scientific studies will be an important factor for manufacturers in developing new products from an environmentally friendly standpoint, thereby accelerating their entry into the growing green products market. Considering environmental factors at the preliminary decision stage before beginning product development and design will eliminate significant health problems that may arise later. (Cinar, 2005). In the market, WBBs are usually sold with dimensions of 210cm x 280cm or 183cm x 366cm with different thicknesses. Furniture is made with the largest dimension ranging from 60cm to 80cm in the furniture industry. The question here is to investigate the FE of WBBs after being processed in the fabrication of furniture using common dimensions. This research aims to analyse the effects of WBB types on FEs for the MDFs and PBs, which are generally used in the solid and composite wood furniture production sector in Türkiye. According to the literature discussed above, the research hypotheses developed as required by the research content are listed below.

H1: There are significant differences between formaldehyde emission measurement values between medium density fibreboard and particleboard wood-based boards.

H2: There are notable differences between formaldehyde emission measurement values for different positions of wood-based boards.

H3: Formaldehyde emission measurement values of medium density fibreboard and particleboard will vary according to the measurement time after preparation of the samples in the laboratory.

MATERIAL AND METHOD

This research determined impacts of board type, temperature and thickness on FE emission from the wood-based samples, which were prepared from different positions of MDF and PB. The obtained emissions were analysed and compared with the limited values of eco indicator as parts per million (ppm). Eco-Indicator 99 (Goedkoop and Spriensma, 2000) was used to check the quantitative data representing FE, which was measured in accordance with TS EN 717-1 (2006) by a MultiRAE multiple gas analyser.

Boards and Adhesive

Two different types of WBBs with 18 mm thickness were tested: 1) MDF, manufactured according to TS EN 622-5 (2008) and 2) PB, manufactured according to TS EN 312 (2005). UF adhesive, code 230026592, W-Leim Plus 3000, Lillestrom, Norway was used for the board production processes. These are the standard materials used in the Türkiye furniture industries. The MDFs and PBs were supplied from Türkiye's main WBB producing factories. Test samples were acquired from the boards of 210cm x 280cm x 0.18cm with respect to TS EN 326-1 (1999). The features of boards and adhesive are given in Table 1 and Table 2.

Table 1. Main features of the boards

Boards	Dimension mm			Weight gr	Density gr/cm^3
	Thickness	Width	Depth		
MDF	18	500	500	3620.58	0.7433
PB	18	500	500	2867.15	0.6433

Table 2. Features of the adhesive (UF)

Adhesives	**Density** (20 ◦C) (g/cm^3)	**Viscosity** (20 ◦C mPas)	**pH** 20 ◦C	Amount of adhesive application (g.m^3)	Amount of solid material %
Ure-Formaldehyde	1.220	16.000 ± 3.000	8.0	180- 200	55±1

Sample Preparation

Twenty samples were prepared from 18 mm thick MDF and PB pieces used in the experiments. Board samples were cut to 500 mm by 500 mm, weighed with a sensible scale, Precia Gravimetrics 312-6200C, in compliance with TS EN 326-1 (1999), and each sample was numbered from 1 to 20, packed with transparent nylon to prevent FE (Figure 1), and stored at the room temperature of 20◦C and 65% humidity to achieve a moisture value equal to indoor physical environment conditions with respect to TS EN 2471 (2005).

Figure 1. Number of samples at positions and keeping samples for experiment

Application of Experiment

FE measurements were taken from the newly produced MDF and PB, which were stored less than 3 days in a large-scale board manufacturing factory. These experiment samples were put into the Climatic Test Cabinet TK600NUVE (2012) at 20◦C and 65% humidity and their corresponding FE values were calculated by a gas analyser at 1, 2, and 3 hour intervals. The experiment samples were prepared from the boards supplied directly from the factory in accordance with EN 13986 (ECS, 2015) and test method TS EN 717-1 (2006). The climatic test cabinet and the multi-RAE multi-gas analyser are given in Figures 2ab.

a. Climatic Test Cabinet b. Multi-RAE Multiple Gas Analyzer

Figure 2.a/b Climatic test cabinet and Multi-RAE Multiple gas analyzer

Statistical Analysis

The data obtained from the F measurements are presented in summary to determine the effects of FE on unprocessed and processed wood-based boards, as well as to compare the findings scientifically and make them more understandable. The measurements of the FE in different positions of the WBBs (MDF and PB) were identified as dependent variables (Table 4), whereas, the exposure time of the WBB within the test cabinet and the selected board position were defined as independent variables. Subsequently, single variance analysis (ANOVA) was used in order to examine the impacts of board positions (Figure 4) and time (1st, 2nd and 3rd hours) on the release of the FE in the WBBs. The mean values were determined to be important in the variance analysis and the results were presented in a graph.

RESULTS

The reliability of the "dependent variables" covering FE values at different positions of WBBs was analysed using Cronbach's Alpha reliability test. Cronbach's Alpha estimates of inner consistency for the two scales, as well as the FE values in Table 4, were as follows: MDF: 0.989 and PB: 0.993 (Table 3). In previous articles by Cronbach (1951) and Panayides (2013), it was clearly expressed that alpha reliability coefficients for all items (1st, 2nd and 3rd hour interval measurements) could be accepted as 'reliable' if they were above 0.70. Thus, this scale may be considered to be good reliable. Reliability analysis results of the variables for FE on WBBs are given in Table 3.

Table 3. Results of the variables' reliability analysis

Boards	Scale Items	Item Reliability	Scale Reliability
MDF	1st hour	0.984	0.989
	2nd hour	0.980	
	3rd hour	0.988	
PB	1st hour	0.992	0.993
	2nd hour	0.986	
	3rd hour	0.992	

Notes: MDF: Medium Density Fibreboard and PB: Particleboard.

The FE measurements in the different positions of the WBBs over a 3 hour period including the distance of mean to limit value (0,10 ppm) are demonstrated in Table 4.

Table 4. FE for different board positions and distance to limit ≤ 0.1 ppm

Boards	Hours ppm				Distance to limit ≤ 0.1 ppm	
	1	2	3	Mean	ppm	%
MDF whole	0.2217	0.2483	0.2663	0.2454	0.1454	145.4
MDF edge	0.1567	0.1833	0.2021	0.1807	0.0807	80.7
MDF centre	0.2867	0.3133	0.3306	0.3102	0.2102	210.2
PB whole	0.2218	0.2540	0.2732	0.2497	0.1497	149.7
PB edge	0.0576	0.0947	0.1103	0.0875	-0.0125	-12.5
PB centre	0.3861	0.4133	0.4361	0.4119	0.3119	311.9

Notes: MDF: Medium Density Fibreboard, PB: Particleboard, Edge: Measurement of the samples on the edge of the PB/MDF, Centre: Measurement of the samples on the middle of the PB/MDF.

According to the results given in Table 4, the release of FE from the edges of the boards is less than the release from the middle parts in both MDF and PB. The differences for the FE in the different positions of the boards were tested with ANOVA. In the analysis results in Table 5, prominent differences between the variables including the measurement results of the FE at different positions of the boards were determined to be statistically important at the $p<0.001$ level for all items related to the research scale.

Table 5. Analysis results of the variables regarding FE in the different positions of the boards (MDF and PB)

FE in Different Positions of Boards		Sum of Squares	df	Mean Squares	F	Sig.	Results
1st hour	Between groups	0.105	1	0.105	14.591	0.000*	$P < 0.001$
	Within groups	0.849	118	0.007			
	Total	0.954	119				
2nd hour	Between groups	0.103	1	0.103	15.005	0.000*	$P < 0.001$
	Within groups	0.812	118	0.007			
	Total	0.915	119				
3rd hour	Between groups	0.116	1	0.116	16.230	0.000*	$P < 0.001$
	Within groups	0.843	118	0.007			
	Total	0.958	119				

*Note: * a: 0.001 is the level of significance.*

The differences between the values of FE depending on the different positions of the boards are illustrated in Figure 3. It can be observed that the PB releases more FE than the MDF with the passing of time for each variable. According to this result, the hypothesis put forward in H1 is supported. This finding indicates that the cellular structure of the fibres used in MDF may be due to the more deformation of the cellular structure of the fibres used in PB. On the other hand, the higher FE content of PB may be related to panel density when compared to MDF. This result may be related to the higher FE content panel density of PB in comparison to MDF. The most significant result is that the samples of P7, 8 and 9 and P12, 13 and 14 in the board's centre, released more FE than P1-6, P10-11 and P15-20, which are placed at board's edge.

According to the results, it is possible to say that less FE is released from the experimental samples cut from the edge parts of both boards than the middle part. At the end, the differences between the different positions on the boards have a critical impact on the values of the FE. This shows that less FE is released from the edges of the untreated (uncut) board compared to the middle portions. These results indicate that the hypothesis advanced in H2 is supported.

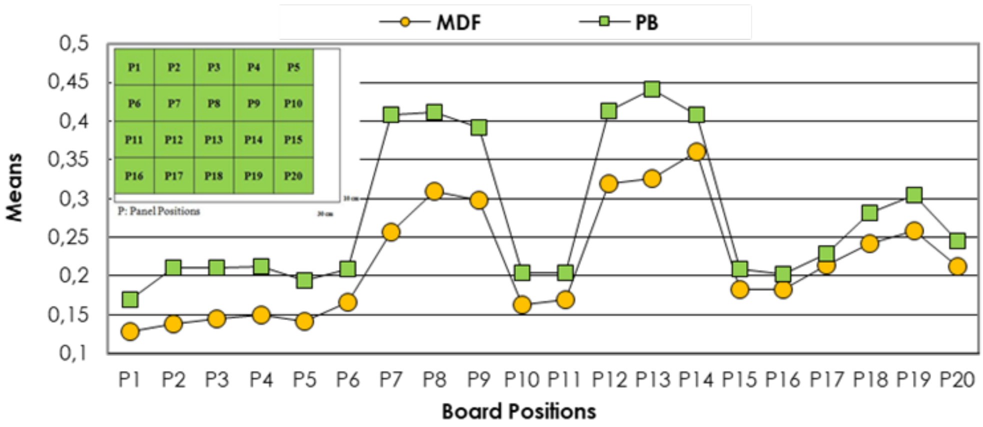

Figure 3. Impact of the different board positions on measurements (MDF and PB)

The differences between the FE values according to the different positions of the MDFs were tested with ANOVA. In the analysis results in Table 6, prominent differences between the variables including the measurement results of the FE in the different board positions were determined to be statistically important at a level of $p < 0.001$ level for all the items (1st, 2nd and 3rd hours) related to the scale.

Table 6. Analysis results of the variables regarding formaldehyde emission in the different positions of the MDF

MDF Board		Sum of Squares	df	Mean Squares	F	Sig.	Results
1st hour	Between groups	0.316	19	0.017	195.677	0.000*	*P* < 0.001
	Within groups	0.003	40	0.000			
	Total	0.319	59				
2nd hour	Between groups	0.285	19	0.015	143.007	0.000*	*P* < 0.001
	Within groups	0.004	40	0.000			
	Total	0.289	59				
3rd hour	Between groups	0.311	19	0.016	77.098	0.000*	*P* < 0.001
	Within groups	0.008	40	0.000			
	Total	0.319	59				

*Note: * α: 0.001 is the level of significance.*

The differences between the FE values depending on the different positions of the MDF are illustrated in Figure 4. As seen, the experimental samples cut from the edge parts of the MDF releases more FE than the experimental samples from the middle part in time. Consequently, the changes between the different positions have an important effect on the FE values. Figure 4 clearly indicate the differences between the release of FE from edge and middle parts of MDF.

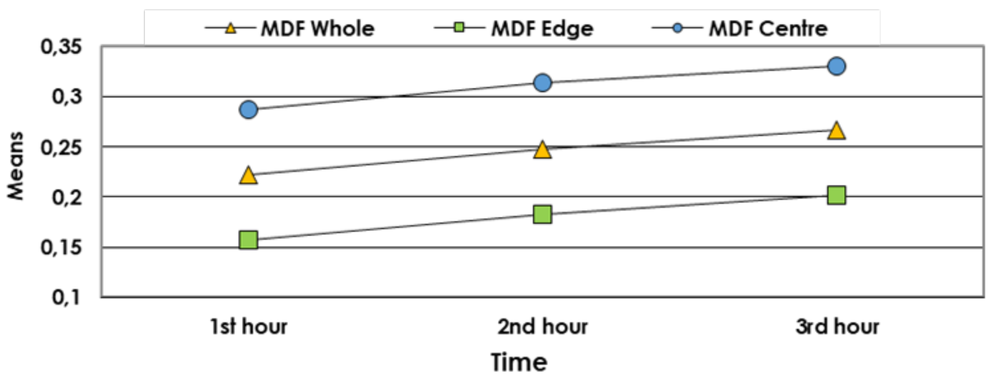

Figure 4. Impact of the different board positions on measurements (MDF)

The differences between the values of FE according to the different positions of the PB were tested with ANOVA. In the analysis results in Table 7, prominent differences between the variables including the measurement results of the FE in the different board positions were determined to be statistically important at a level of $p < 0.001$ level for all the items (1st, 2nd and 3rd hours) related to the scale.

Table 7. Analysis results of the variables regarding formaldehyde emission in the different positions of the PB

	PB Board	Sum of Squares	df	Mean Squares	F	Sig.	Results
1st hour	Between groups	0.528	19	0.028	475.994	0.000*	*P* < 0.001
	Within groups	0.002	40	0.000			
	Total	0.530	59				
2nd hour	Between groups	0.520	19	0.027	432.093	0.000*	*P* < 0.001
	Within groups	0.003	40	0.000			
	Total	0.522	59				
3rd hour	Between groups	0.520	19	0.027	304.011	0.000*	*P* < 0.001
	Within groups	0.004	40	0.000			
	Total	0.523	59				

*Note: * a: 0.001 is the level of significance.*

The differences between the FE values depending on the different positions of the PB are illustrated in Figure 5. As shown, for each variable according to the time, the experimental samples cut from the edge parts of the PB releases more FE than the experimental samples from the middle part. As a result, the differences between the positions have an important effect on the FE values. Figure 5 clearly indicates the differences between the release of FE from edge and middle parts of PB.

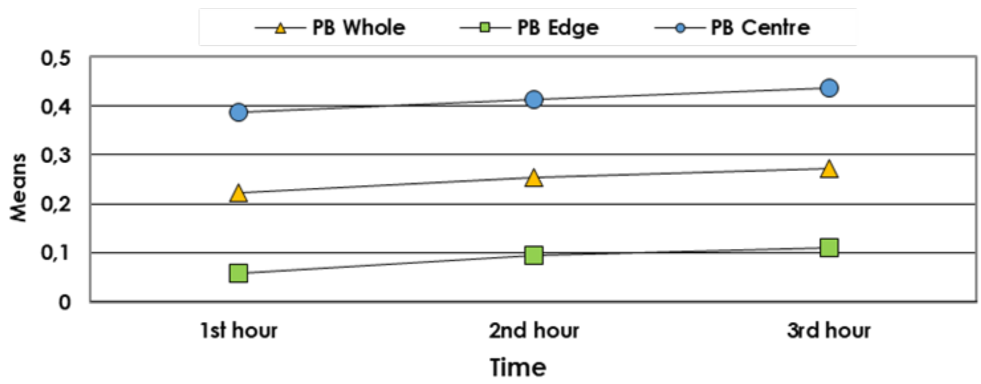

Figure 5. Impact of the different board positions on measurements (PB)

The results provided in Table 6 and 7 show that the hypothesis put forward in H3 is supported.

CONCLUSIONS AND SUGGESTIONS

The results of this research yields that the cut parts from the wood-based boards (WBBs) is significant in terms of the formaldehyde emission (FE) because of the place overall position of the boards. Following are some possible conclusions:

- The highest FE value (0.4119 ppm) was determined in the samples taken from the centre, while the lowest FE value (0.0875) was obtained from the samples taken from the particleboard (PB) edges.
- The highest FE value (0.3012 ppm) was obtained from the samples taken from the centre, the lowest FE value (0.1807 ppm) was obtained from the samples

taken from the edges of medium density fibreboard (MDF).

- The PBs have a higher environmental effect (0.2497 ppm) than the MDFs (0.2454 ppm).

- While the farthest value to the limit values (0.10 ppm) was 311% for the central samples of PB, the closest value was determined as -12.5% for the edge samples of PB.

- Based on these results;

- By keeping the parts to be cut from the edges of the boards waiting for less time, they can be assembled more quickly.

- The parts to be cut from the inner parts of the boards can be waited for a while until the formaldehyde emission reaches the limit values before production and assembly, and then processing can be started.

In the selection of WBBs and complementary elements, which are widely used in various design projects in the building and furniture industry, their possible negative effects on humans and the environment must be considered. It should be noted that the ratio of organic chemicals in these panels should not exceed the limit values published by the World Health Organization. To reduce the gas emission in indoor environments, it is strongly recommended to wait for a certain period of time after the panels are cut in the manufacture of panel furniture, and then it is recommended to start the processes such as veneer covering coating and edge banding etc. (Cinar et al., 2018). In the short term, it can be expected that the concept of green design will be more prominent in project solutions, as it is now with universal design. Consequently, more research on the impact of some design decisions regarding product and environmental quality should be conducted, and future work in this area should be encouraged.

Conflict of Interest
No conflict of interest was declared by the authors.

Authors' Contributions
The authors contributed equally to the study.

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Ethics Committee Approval
Ethics committee approval was not required for this article.

Legal Public/Private Permissions
In this research, the necessary permissions were obtained from the relevant participants (individuals, institutions, and organizations) during the survey and in-depth interviews.

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