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Abstract: This study aimed to determine the best manufacturing variables for the high physical and mechanical properties, and formaldehyde emission of particleboards produced from E_1 type adhesive. In the production of particleboards, two different press temperatures, press times, pressures and three different adhesive use ratios were used. The best manufacturing variables were determined for the particleboard produced from E_1 type adhesive. The effects of these manufacturing variables on formaldehyde emission, bending strength, internal bonding strength and thickness swelling were investigated. According to the results, when the E_1 type adhesive was employed, the use of 11% and 9% adhesive use ratios for the outer and middle layers, respectively, 200°C press temperature, 150 s press time and 32.5 kg/cm^2 pressure were found to be enough. It was suggested that at 180°C, the particleboards required 150 s press time and 35 kg/cm^2 pressure. It was found that in the production of E_1 type particleboard, the use of low emission adhesive was not enough, and all of the production parameters should be taken into account together. In addition, it was concluded that the amount of formaldehyde emission of manufactured particleboards should be low. Equally, the particleboards should meet the required physical and mechanical properties as stated in the relevant standards.

Key Words: E_1 type particleboard, technological properties, manufacturing variables

E_1 Tipi Yongalevha Üretimini Etkileyen Faktörler

Özet: Çalışmada, E_1 tipi tutkal kullanılarak üretilen yongalevhalarda yüksek fiziksel ve mekanik dirençler ile düşük formaldehid emisyonu değerlerine ulaşmak için en uygun üretim şartlarının belirlenmesi amaçlanmıştır. Yongalevhaların üretilmesinde iki farklı pres sıcaklık, süre ve basıncı ile üç farklı tutkal kullanım oranı uygulanmıştır. E_1 tipi tutkal kullanılarak üretilen levhalarda en uygun üretim koşulları belirlenerek, bu koşulların; formaldehid emisyonu, eğilme direnci, yüzeye dik çekme direnci ve kalınlık artışı üzerine etkileri araştırılmıştır. Elde edilen sonuçlara göre; yongalevha üretiminde E_1 tipi tutkal kullanılması halinde; dış tabakalar için % 11, orta tabaka için ise % 9 oranında tutkal kullanılarak, 200 °C pres sıcaklığı, 150 sn pres süresi ve 32.5 kg/cm^2 pres basıncı uygulanması yeterli olmuştur. Pres sıcaklığının 180 °C olarak uygulanması durumunda ise pres süresinin 150 sn ve pres basıncının 35 kg/cm^2 olması gerektiği belirlenmiştir. E_1 tipi yongalevha üretiminde düşük emisyonlu tutkal kullanımının yeterli olmadığı, bütün üretim koşullarının birlikte ele alınması gerektiği saptanmıştır. Ayrıca, üretilen levhaların formaldehid emisyonunun düşük olması yanında fiziksel ve mekanik özellilerinin de standartlara uygun olması gerektiği sonucuna varılmıştır.

Anahtar Sözcükler: E_1tipi yongalevha, teknolojik özellikler, üretim faktörleri

Introduction

Formaldehyde is one of the world's most ubiquitous chemicals. It is a simple chemical compound made of carbon, hydrogen and oxygen (CHOH) which is produced naturally by plants, animals and humans as part of the normal life process. It is also generated as a by-product of incomplete combustion in car exhaust and cigaratte smoke (Vyse, 1993).

It is used in consumer products such as shampoo, lipstick, toothpaste, vaccines, disinfectants and permanent press clothing. Formaldehyde provides an important source of single carbon molecules in the production of polymer adhesives used in the manufacture of many products, including pressed wood products such as particleboard (Ettore et al., 1988).

Urea formaldehyde (UF) adhesives are used in much of the particleboard worldwide. UF adhesives are easy to work with, provide strong, durable bonds and are economical. Formaldehyde acts as the cross linker or polymerizer in UF adhesives.

Wood based panels are now widely used in construction and furniture and are probably the most important source of formaldehyde in indoor air. In the 1960 s and early 70 s, the urea formaldehyde resins used in the manufacture of particleboard had molar ratios of urea to formaldehyde ranging around 1:1.6 to 1:1.8. With the first oil crisis in 1972, and the ensuring pressure to improve insulation and reduce ventilation in buildings, problems of formaldehyde odour in buildings began to arise and work was started to develop methods of tests and to develop resins of low formaldehyde content.

The aim of this study was to limit formaldehyde emission. However, the process parameters using to limit formaldehyde emission must not reduce the other technological properties of particleboard. For this reason, formaldehyde emission, and the physical and mechanical properties were determined together in this study.

Materials and Methods

In the production of particleboards, beech (50%), pine (40%) and poplar (10%) woods and urea formaldehyde adhesive were used. The characteristics of the urea formaldehyde adhesive used are given in Table 1.

Table 1. Characteristics of urea formaldehyde adhesive.

Characteristics	Urea Formaldehyde Adhesive
Solid Content	65%
Gravity at 20°C	1.285 g/cm^3
Viscosity at 20°C	500 cps
pH at 20°C	7.5-8.5
Gel Time at 100°C	45-60 s
Free Formaldehyde	0.15 max.%
Formaldehyde/Urea Mole Ratio	1.13

Raw materials were chipped and screened. After these processes, particles were dried down to 3% moisture content. As a hydrophobic substance 32% of paraffin solution, which was 4.67% and 4.56% of the oven dry weight of adhesive in the outer layers and middle layer respectively, was used and as a hardener 20% of ammonium chloride solution, which was 3.25% and 10.14% of the oven dry weight of adhesive in the outer layers and middle layer, was used. Particleboards produced were 280 x 210 x 1.8 cm in dimension and 0.70 g/cm^3 in specific gravity. Produced particleboard types are given in Table 2.

Table 2. Particleboard types.

Types	Press Temperature °C	Press Time s	Pressure kg/cm^2	Adhesive Use Ratio in the Outer Layers*	Adhesive Use Ratio in the Core Layer*
A	180	135	32.5	9.5	8.5
B	180	150	32.5	9.5	8.5
C	200	135	32.5	9.5	8.5
D	200	150	32.5	9.5	8.5
E	180	135	35.0	9.5	8.5
F	180	150	35.0	9.5	8.5
G	200	135	32.5	11.0	9.0
H	200	150	32.5	11.0	9.0
I	200	135	32.5	9.0	7.0
J	200	150	32.5	9.0	7.0

*based on the oven dry weight of the particles.

After pressing, boards were conditioned to constant mass in an atmosphere of 60-70% relative humidity and at a temperature of 18-22°C. Thickness swelling (TS) in 2 h immersion of the boards was measured according to the ASTM-D 1037 (1978) standard. British Standard BS 5669 (1979) was followed to determine static bending (SB) and internal bond (IB) strengths. The formaldehyde emission (FE) was determined according to the DIN EN 120 (1984) standard. Results of the tests were evaluated by multiple variation analysis and Duncan tests with a 95% confidence level. For TS, SB, and IB, 30 specimens were tested, and for FE testing six specimens were prepared by random selection.

Results and Discussion

Some of the technological properties of particleboards are given in Table 3.

The effects of press temperature and press time on the technological properties of the particleboards are given in Table 4. According to multiple variation analysis, press temperature and press time were found to affect on the technological properties of particleboard.

The effects of press time and pressure on the technological properties of particleboards are given in Table 5. According to multiple variation analysis, pressure and press time were found to affect on the technological properties of particleboard. The effects of press time and

Table 3. Some technological properties of the particleboards.

Types	SB N/mm2	IB N/mm2	TS %	FE mg HCHO/100 g
A	12.51	0.16	11.76	9.67
B	12.82	0.20	11.16	8.75
C	14.13	0.31	10.32	7.90
D	15.00	0.36	9.43	7.08
E	13.57	0.23	10.94	8.23
F	13.86	0.28	10.40	7.96
G	15.75	0.39	9.00	10.43
H	16.61	0.43	8.45	9.70
I	11.49	0.10	13.24	6.03
J	12.09	0.13	12.69	5.69

Table 4. Multiple variation analysis on effects of press temperature and press time on the technological properties (A, B, C, D).

Tests	Source of Variation	Sum. of Squares	d.f.	Mean Square	F-ratio	Sig. Level
	A-Press Temperature	12.31	1	12.31	38.44	**
	B-Press Time	34.48	1	24.48	125.87	***
SB	Int. AxB	8.36	1	8.36	11.25	**
	Residual	15.16	116	0.13		
	Total	70.31	119			
	A-Press Temperature	0.17	1	0.17	132.68	***
	B-Press Time	0.64	1	0.64	155.45	***
IB	Int. AxB	0.08	1	0.08	4.48	*
	Residual	0.21	116	0.00		
	Total	1.10	119			
	A-Press Temperature	22.45	1	22.45	78.11	**
	B-Press Time	85.94	1	85.94	555.79	***
TS	Int. AxB	1.15	1	1.15	2.35	*
	Residual	21.35	116	0.18		
	Total	130.89	119			
	A-Press Temperature	18.62	1	18.62	111.32	***
	B-Press Time	12.65	1	12.65	105.46	***
FE	Int. AxB	1.13	1	1.13	4.86	*
	Residual	15.84	20	0.79		
	Total	48.24	23			

Note: ***p < 0.001, **p < 0.01, *p < 0.05

adhesive use ratio on the technological properties of particleboards are given in Table 6.

According to multiple variation analysis, press time and adhesive use ratio were found to affect on the technological properties of particleboard.

Increasing press temperature, time, pressure, and adhesive use ratio caused a significant improvement in SB and IB. This might be due to interference in the curing of the adhesive, reduced wettability of the particle surface or limitation of diffusion and/or spreading of the adhesive

Table 5. Multiple variation analysis on effects of press time and pressure on the technological properties (A, B, E, F).

Tests	Source of Variation	Sum. of Squares	d.f.	Mean Square	F-ratio	Sig. Level
	A-Pressure	16.58	1	16.58	22.13	**
	B-Press Time	21.12	1	21.12	115.24	***
SB	Int. AxB	7.75	1	7.75	6.71	*
	Residual	10.02	116	0.08		
	Total	55.47	119			
	A-Pressure	0.28	1	0.28	33.47	**
	B-Press Time	0.73	1	0.73	128.64	***
IB	Int. AxB	0.05	1	0.05	3.08	*
	Residual	0.33	116	0.00		
	Total	1.39	119			
	A-Pressure	35.58	1	35.58	52.46	**
	B-Press Time	93.22	1	93.22	475.83	***
TS	Int. AxB	2.24	1	2.24	3.27	*
	Residual	17.31	116	0.14		
	Total	148.35	119			
	A-Pressure	24.48	1	24.48	67.74	**
	B-Press Time	37.62	1	37.62	122.18	***
FE	Int. AxB	4.08	1	4.08	4.11	*
	Residual	16.01	20	0.80		
	Total	82.19	23			

Table 6. Multiple variation analysis on effects of press time and adhesive use ratio on the technological properties (C, D, G, H, I, J).

Tests	Source of Variation	Sum. of Squares	d.f.	Mean Square	F-ratio	Sig. Level
	A-Adhesive Use Ratio	32.14	2	16.07	163.21	***
	B-Press Time	16.25	1	16.25	31.24	**
SB	Int. AxB	6.10	2	3.05	3.45	*
	Residual	9.95	174	0.05		
	Total	64.44	179			
	A-Adhesive Use Ratio	0.96	2	1.87	141.55	***
	B-Press Time	0.42	1	0.42	46.58	**
IB	Int. AxB	0.18	2	0.09	2.94	*
	Residual	0.31	174	0.00		
	Total	1.87	179			
	A-Adhesive Use Ratio	45.58	2	22.79	63.34	**
	B-Press Time	88.14	1	88.14	346.68	***
TS	Int. AxB	2.12	2	1.06	3.07	*
	Residual	19.26	174	0.11		
	Total	155.10	179			
	A-Adhesive Use Ratio	96.38	2	48.19	168.33.	***
	B-Press Time	35.12	1	35.12	72.13	**
FE	Int. AxB	5.42	2	2.71	2.11	*
	Residual	18.46	30	0.61		
	Total	155.38	35			

within the particles and over the particle surface (Akbulut, 1995). Similar results were reported by Philıppou et al. (1982), Rayner (1969), Myers (1984), and Witman (1985).

According to BS 5669, with which the SB was tested, boards of general use have 12.5 N/mm^2 SB for 20 mm thickness. A-B-C-D-E-F-G-H type boards had higher SB values than the standard value. The acceptable level of IB values is 0.25 N/mm^2 for 20 mm thickness according to the BS 5669. C-D-F-G-H type boards had the required level of IB values.

The increase of press temperature, press time, pressure and the reduction of adhesive use ratio caused a significant improvement in formaldehyde emission. This can be explained in that formaldehyde emission increases in the press stage due to increases in press temperature, time and pressure. Therefore, the amount of formaldehyde emission was found to be lower in the produced particleboards. Formaldehyde is the chemical compound of urea formaldehyde adhesive. It is used to provide strong and durable bonds. For these reasons, decreasing the adhesive use ratio caused a significant reduction in formaldehyde emission, as well as physical and mechanical properties. Similar results were reported by Kalaycıoğlu and Çolakoğlu (1994), and Myers (1984). C-D-F-I-J type boards were E_1 type particleboards.

Increasing the resin content, press temperature, press time and pressure resulted in the reduction of thickness swelling. This might be due to interference in the curing of the adhesive, reduced wettability of the particle surface or limitation of diffusion and/or spreading of the adhesive within the particles and over the particle surface. The same results were reported by Philippou et al. (1982). According to the ASTM-D 1037, the acceptable level of TS is max. 6% in 2 h immersion. All of the boards had higher TS than the standard value. For this reason, particleboard surfaces and edges should be coated (Nemli, 2000).

According to the results, E_1 type particleboards produced from urea formaldehyde adhesive, which has 1.13 formaldehyde/urea mole ratio (adhesive use ratio: 8.5 / 9.5), can be produced and have the required level of mechanical properties at 200°C press temperature, 135-150 s press time and 32.5 kg/cm^2 pressure. At 180°C, the particleboards require 150 s press time and 35 kg/cm^2 pressure.

C-D-F type particleboards can be employed for general purposeuse. They have the required levels of IB, SB and FE. However because of their high TS values, they should be coated.

Conclusion

Wood based panels such as particleboard, medium density fiberboard and plywood are widely used in construction and furniture and are probably the most important source of formaldehyde. Because of formaldehyde's reactivity and pungent odour, formaldehyde has been regulated in the workplace for many years in many countries. Although regulations within Europe have some way to go before uniformity is achieved and there will be further changes, the situation and trends are becoming clearer. The toxic effects of formaldehyde resulted in the start of numerous research projects, epidemiology studies and debates to determine and agree the significance of this in relation to formaldehyde and manage how formaldehyde should be controlled to ensure safety industrially.

There are a number of ways that formaldehyde emission from particleboards can be reduced. Some occur naturally, some are brought about by the manufacturer, and some can be implemented by the end user. Several of the more common include: aging, formaldehyde scavengers, coating and laminates (Aston, 1987).

In this study, it was stated that increasing press temperature, press time and pressure improved the technological properties of particleboard. Although increasing the adhesive use ratio improved the physical and mechanical properties, it caused an increase in formaldehyde emissions.

The aim of this study was to limit formaldehyde emissions. However the process parameters used to limit formaldehyde emission must not reduce the other technological properties of particleboard. For this reason, formaldehyde emission, and physical and mechanical properties should be determined together.

According to our work, it was found that in the production of E_1 type particleboard, low emission adhesive use was not enough, and all of the production parameters should be taken into account together. In addition, it was concluded that the amount of formaldehyde emission from manufactured particleboards should be low. Equally the particleboards should meet the required physical and mechanical properties stated by relevant standards.

Additional work is needed to determine the effects of the other process parameters, such as board thickness, particle geometry, board moisture content, particle drying temperature, raw material type, board density, formaldehyde scavengers, aging, hardener type and amount, coatings and laminates, on the technological properties of E_1 type particleboard.

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