POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

Study of the effect of alfa-x to the urea formaldehyde adhesive on plywood

Kontrplaklarda üre formaldehit tutkalına ilave edilen Alfa-x'in etkisinin İncelenmesi

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Özalp M., "Study of the effect of alfa-x to the urea formaldehyde adhesive on plywood", ***Politeknik Dergisi***, 25(2): 513-518, (2022).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.769304

Study of the Effect of Alfa-x to the Urea Formaldehyde Adhesive on Plywood

Highlight

- *It was found that that the addition of Alfa-x to the adhesive mixture used on the plywood slightly decreased strength properties of plywood that is bonded using this resin*
- *It was concluded that, since formaldehyde emissions hold a significant importance for human health, Alfa-x, which decrease the levels of this emission*

Graphical Abstract

Kontrplaklarda Üre-formaldehit (UF) tutkalına ilave edilen Alfa-x'in formaldehit emisyonu ve mekanik özellikleri üzerine etkileri incelenmiştir.

Figure. Experimental design

Aim

This study investigated the effect of adding Alfa-x to the of urea-formaldehyde (UF) adhesive.

Design & Methodology

The content of free formaldehyde, withdrawal shear strength, and bending strength were studied in the experimental plywood.

Originality

Alfa-x was added to the adhesive (UF) in 0, 10, and 20 wt% ratio of the total amount of the solid content.

Findings

There were higher withdrawal-shear strength and bending strength values of the ekaba plywood than the poplar plywood values.X There were higher values of free formaldehyde in the ekaba plywood than the poplar plywood, and the free formaldehyde content value in both samples was reduced by adding Alfa-x to the adhesive.

Conclusion

Formaldehyde emission, which is important for human health, without reducing the mechanical properties of plywood, has been successfully reduced.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Formaldehit Tutkalına İlave Edilen Alfa-x Etkisinin İncelenmesi

Araştırma Makalesi / Research Article

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(Geliş/Received : 14.07.2020 ; Kabul/Accepted : 14.09.2020 ; Erken Görünüm/Early View : 02.10.2020)

ÖZ

Bu çalışmada, üre-formaldehit (UF) tutkalına ilave edilen Alfa-x'in formaldehit emisyonu ve mekanik özellikleri üzerine etkileri incelenmiştir., üre-formaldehit tutkal karışımlarına belirli miktarlarda alfa-x ilave edilerek üç katlı kavak (Populus x eureamericana) ve ekaba (Tetraberlinia bifoliolata) kontrplakları hazırlanmıştır. Üretilen kontrplaklarda formaldehit emisyonu, çekme-makaslama ve eğilme direnci deneyleri yapılmıştır. Tutkal karışımına ilave edilen ilen Alfa-x kontrplak mukavemet özelliklerini çok az oranda düşürmüştür. Formaldehit emisyonu değerlerini ise istatistiksel anlamda önemli oranda düşürmüştür.

Anahtar Kelimeler: Formaldehit emisyonu, konik yay, alfa-x, eğilme direnci, çekme makaslama direnci.

Study of the Effect of Alfa-x to the Urea Formaldehyde Adhesive on Plywood

ABSTRACT

This study investigated the effect of adding Alfa-x to the of urea-formaldehyde (UF) adhesive. The content of free formaldehyde and the bonding specifications were examined. The three-layered plywood of poplar (*Populus* x *eureamericana*) and ekaba (*Tetraberlinia bifoliolata*) was prepared by adding alfa-x to adhesive mixtures in specified amounts. The content of free formaldehyde, withdrawal shear strength, and bending strength were studied in the experimental plywood. The strength specifications of plywood bonded with this resin were slightly reduced by adding the Alfa-x to the adhesive mixture. There was also a moderate decrease in the content of free formaldehyde.

Keywords: Content of free formaldehyde, alfa-x, plywood, bending strength, withdrawal shear strength.

1. INTRODUCTION

It is very important to have wood and surfaces in the wood industry. Urea formaldehyde adhesive is generally used because it is cheap and easily available in plywood production [1].

Synthetic resins used in plywood production are substances harmful to human and environmental health. Formaldehyde, which is an important component of synthetic resins, separates from the material at the place of use and mixes with air and creates adverse effects. Formaldehyde has an irritating effect on the eye and nasal mucosa. It can also cause shortness of breath and allergic skin conditions [2].

Formaldehyde spreads from wood-based panels bonded with amino and phenolic resins during production and end use. The amount of formaldehyde released from wood-based panels is affected by exterior factors such as air humidity, air exchange and temperature and production conditions, as well as endogenous factors such as raw material types and resin types [3]. There are several reports about the negative effects of formaldehyde on human health [4,5,6].

Indoor products including core panels of doors, sub flooring, and furniture are made using composite wood products including plywood, particleboard, and MDF [7]. One concern for these products is air pollution in residential buildings, which causes health problems. Building materials and construction products cause emit pollutants including acetaldehyde and formaldehyde [8]. The products containing formaldehyde such as plywood, oriented strand board (OSB), resins, insulating material, fabrics, and glues are the main anthropogenic sources affecting humans in closed environments [9]. Large amounts of formaldehyde are manufactured in industry and widely applied. The terpenoid and ozone reaction in the indoor environment produces formaldehyde [10]. For this reason, wood adhesives without formaldehyde should be developed based on industrial safety standards. There should be emphasis on the replacement or reduction of formaldehyde contents in adhesives [11,12,13,14].

A study investigated the volatile acetic acid and formaldehyde emissions effect on the plywood exposed to boric acid and borax. Borax reduces formaldehyde emissions, while boric acid increases them [15]. Any material that creates a panel causes volatile organic compound (VOCs) emissions. Recently, formaldehyde emission from UF adhesive has been examined [16]. To evaluate the health and environmental effects of the board materials based on wood, formaldehyde emission should be taken into account [17]. An effective and

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simple approach that suppresses the emission of formaldehyde from plywood can be provided using natural compounds including vanillin, catechin, and urea [18]. The adhesive strength in boards of the laminated veneer lumber (LVL) can be enhanced by adding boric acid to melamine-urea-formaldehyde adhesive [19]. There has been extensive study on the boron treatment effect on the dimensional, biological, and mechanical characteristics of the wood-based materials. According to measurements using the desiccator method, formaldehyde infused with borax decreases formaldehyde emission caused by the plywood panels [20]. Furthermore, there have been studies on the effect of adding borax pentahydrate to urea-formaldehyde (UF) adhesive on the plywood bonding characteristics and its content of free formaldehyde. The plywood withdrawal shear strength and bending strength are not statistically affected by adding borax pentahydrate, but the content of free formaldehyde is reduced [21]. Formaldehyde content of decorative boards based on larch bark (0.6 g/cm3) was analyzed when bonded with five different types of adhesive systems: urea-formaldehyde, polyvinyl acetate, the mixture of 70% urea-formaldehyde + 30% polyvinyl acetate, polyurethane, and tannin-based adhesive. A self-agglomerated board was also analyzed. In the case of boards bonded with tannin-based adhesive, this natural polymer acted as a formaldehyde scavenger [22].

The aim of this study is to investigate the effect of alfa-x in decreasing the free formaldehyde content in urea-formaldehyde adhesive which is used in the production of plywood, and to determine the ideal mixture ratio by researching the effect of the alfa-x that is added into the adhesive mixture in different ratios on the mechanical characteristics of the material.

2. MATERIAL AND METHOD

2.1. Wood material

To produce plywood in experiments, poplar (*Populus* x *eureamericana*) and ekaba (*Tetraberlinia bifoliolata*) tree species were used for constructing the veneers. The veneers were made from one lumber for both trees types to ensure the biological and chemical properties of the tree species found in veneers.

2.2. Adhesive

Plywood was produced with urea-formaldehyde (UF) adhesive. Approximately 90% of wooden boards are produced using this plywood, as it requires a short setting term in the hot-press, and it is transparent, easy, and inexpensive. The urea-formaldehyde 2265 adhesive (Polisan Chemical Industry Company, Kastamonu, Turkey) technical properties were as follows: storage for 90 days at 20 °C, viscosity at 20 °C is 100 to 200 (cps), density at 20 °C is 1.22 to 1.23 (g/cm^3), rate of solid material (wt%) is 55 ± 1, pH at 20 °C is 7.5 to 8.5, molar ratio (formaldehyde /urea) is 1.35, and free formaldehyde (%) is at most 0.8.

A rolling press was used by applying 180 g/m^2 of the adhesive double glue line on the sample surface. The test plywood was produced using urea formaldehyde (UF) adhesive with a solid content of 55 wt%. A hardening agent, *i.e*., 15 wt% of ammonium chloride (NH_4Cl), was added to 10 wt% of the liquid adhesive. An additive of wheat flour was added to the adhesive in 55 wt% of the solid matter.

The Alpha-X antifire is aphosphate based product with a proprietary formulation. Its unprecedented effectiveness as a flam-reterdant is a result of its innovative formulatıon including also special coupling agents. Usable as an additive in the production process of different materials, it will be homogenously distributed in the material and imbue it with its unrivaled fire-protection capabilities from the very beginning. It surpasses all requirements demanded for modern flame reterdants: absolutely effective, universally applicable and finally safe. The Alpha-X antifire powder includes special titanium-derived coupling agents which react with free protons at the inorganic interfere resulting in the formation of organic-titanium mono-molecular layers on the inorganic surface. Typically, titanate-treated inorganics are hydrophobics, organophilic, and oganofunctional. Fillers may be pretreated or treated in used in polymers, titanates: increase adhesion; reduce embrittlement; allow higher filler loading; optimize particulate dispersion; increase flow filled and unfilled polymers at lower process temperature; prevent phase seperation. The use coupling agents (<10%) are mainly compose of pyrophoshato-O, silicon dioxide and titandioxide.

The Alpha-X antifire is used as a complement to the polymer and is added to the production processes of various products. It is used in thermoplastic, paint, cable, synthetic, membrane, and wood-based boards. It is effective up to 1500 °C against flammability. Alfa-x was added to the adhesive in 0, 10, and 20 wt% ratio of the total amount of the solid content. The technical properties of the Alpha-x are given in Table 1.

Table 1. Technical Properties of the Alpha-X Chemicals

Appearance	Dry powder
Color	White
Granular size	<5 0 μm
pH	3.74
Relative density	0.847 (g/cm^3)
Odor	None
Storage	Cool, dry place; protected from moisture
Web	www.alfa-x.eu (info@eurosis.de)

2.3. Bending strength

The specifications of BS EN 310 (1993) were followed to analyze the plywood bending strength [23]. The samples measuring 50 mm in width and 150 mm in length were prepared for examination (10 replicates) and the axis of length was in the same direction with the exterior layers fiber direction. Then, the samples were adjusted to the new climate in the air conditioning cabin at relative humidity of 65% and temperature of 20°C. The sample bending strength was calculated with the following method:

$$\sigma_e = \frac{3.f.l}{2.b.a^2} \tag{1}$$

where σ_e is the bending strength (N/mm^2), *f* is the maximum force at the breakage moment (N), *l* is the distance of the support points (mm), *b* is the sample piece width (mm), and *a* is the sample piece thickness (mm).

2.4. Withdrawal-shear strength

BS EN 314-2 (1993) was followed to determine the withdrawal-shear strength [24]. The samples measured 250 mm in width and 100 mm in length were prepared for examination (10 replicates) such that the axis of length was in the same direction with the exterior layers fiber direction. The samples were adjusted to the new climate in the air conditioning cabin at relative humidity of 65% and temperature of 20 °C. The withdrawal-shear strength was calculated with the following equation.

$$\sigma_w = \frac{F}{A} = \frac{F}{(b.l)} \tag{2}$$

where σ_w is the withdrawal-shear strength (N/mm^2), *F* is the maximum force at the breakage moment (N), *b* is the cross-section sample width (mm), and *l* is the cross-section sample length (mm).

The universal test device for mechanical experiments is given in fig.1.

Figure 1. Universal test device

2.5. Free formaldehyde Measurements

The content of free formaldehyde (in 3 replicates) was calculated for measurement of free formaldehyde in the laboratory at the quality control management department of Kastamonu Integrated Company (Kastamonu, Turkey). The TS 4894 EN 120 (1999) was applied for conducting the measurements [25].

The perferator test device in which formaldehyde emission tests are performed is given in fig.2.

Figure 2. Perferator test device

2.6. Preparation of experimental samples

The middle layer measuring 2.2 mm and also outer layers ekaba and poplar veneers measuring 1.1 mm were employed to produce a three-layered plywood in size of 80 × 80 × 0.4 cm. The electric heated hydraulic press with the press area of 150 × 300 cm^2 was applied to press the boards. The press area pressure was set at 10 (kg/cm^2), and the temperature was 110 °C according to the applicable standards. Pressing lasted for 5 min.

3. RESULTS AND DISCUSSION

Table 2 shows the withdrawal-shear strength and bending strength average values in the ekaba and poplar plywood, which was produced to determine the effect of adding Alfa-x to the adhesive mixture in different ratios

Table 2. Withdrawal-Shear Strength and the Bending Strength Values (N/mm^2)

Wood Type	Values	Bending Strength Values			Withdrawal-shear Strength Values		
		Alfa-x ratio (wt%)			Alfa-x ratio (wt%)		
		0	10	20	0	10	20
Ekaba	Max.	97.68	97.38	96.94	13.15	12.48	12.12
	Min.	92.64	91.52	90.83	12.01	11.87	10.99
	Average	95.53	94.28	93.88	12.44	12.15	11.89
	Stand. Dev.	1.33	1.47	1.44	0.30	0.16	0.37
Poplar	Max.	81.12	78.47	75.15	9.75	9.78	9.61
	Min.	67.00	68.41	69.98	9.34	9.13	8.98
	Average	74.07	73.39	72.72	9.53	9.44	9.38
	Stand Dev.	3.48	2.37	1.48	0.12	0.16	0.22
Sample Number		10	10	10	10	10	10

There were higher withdrawal-shear strength and bending strength values of the ekaba plywood than the poplar plywood values. However, the withdrawal-shear strength and bending strength values of both samples types were reduced by adding the Alfa-x to the adhesive. Variance analysis was used to examine the interaction between these obtained values, as shown in Tables 3 and 4. For the poplar and ekaba plywood, the variance analysis results showed an insignificant effect of adding the Alfa-x to the adhesive mixture on the bending strength, with a 5% error margin. The effect of adding the alfa-x to the adhesive mixture on the withdrawal-shear strength was slightly significant, with a 5% error margin.

Table 5 shows the content of free formaldehyde. The content of free formaldehyde in plywood was reduced by adding the alfa-x to the adhesive mixture. There were higher values of free formaldehyde in the ekaba plywood than the poplar plywood, and the free formaldehyde content value in both samples was reduced by adding Alfa-x to the adhesive. Variance analysis was used to examine the interaction between the values, and Table 6 shows the obtained results. There was a relatively significant effect of adding the Alfa-x to the adhesive mixtures in ekaba and poplar plywood on the content of free formaldehyde, with a 5% error margin.

Table 3. Results of the Bending Strength Variance Analysis

Source of Variance	Df	Sum of Squares	Mean Squares	F test	P
Tree Type	1	6723.38	6723.38	1534.012	0.000
Alfa-x ratio (wt%)	2	23.007	11.504	2.625	0.082
Wood*Alfa-x	2	0.782	0.391		
Error	54	236.67			
Corrected total	59	6983.84	4.383	0.089	0.915

Table 4. Results of Withdrawal-Shear Strength Variance Analysis

Source of Variance	Df	Sum of Squares	Mean Squares	F test	P
Tree Type	1	110.134	110.134	1857.433	0.000
Alfa-x (wt%)	2	1.22	0.625	10.542	0.000
Wood*Alfa-x	2	0.40	0.200	3.373	0.042
Error	54	3.202	0.059		
Corrected total	59	114.986			

Table 5. The Free Formaldehyde Content Values

Wood type	Values	Content of formaldehyde (mg/100g) Alfa-x ratio (wt%)		
		0	10	20
Ekaba	Max.	45.81	23.17	21.79
	Min.	45.11	22.81	21.01
	Average	45.46	22.19	21.40
	Stand. Deviation	0.35	0.18	0.40
Poplar	Max.	38.22	29.03	21.88
	Min.	38.10	28.90	21.63
	Average	38.15	28.97	21.78
	Stand. Deviation	0.06	0.06	0.13

Table 6. Results of Free Formaldehyde Content Variance Analysis

Source of Variance	Df	Sum of Squares	Mean Squares	F test	P
Tree Type	1	0.445	0.445	7.844	0.016
Alfa- x ratio (wt%)	2	1357.17	678.58	11963.37	0.000
Wood*Alfa-x	2	133.42	66.71	1176.08	0.000
Error	12	0.681	0.057		
Corrected total	17	1491.72			

4. CONCLUSIONS

Plywood is mandatory in places where robustness and resistance are at stake. In this study, formaldehyde emission, which is important for human health, without reducing the mechanical properties of plywood, has been successfully reduced.

1. There were higher withdrawal-shear strength and bending strength values of the ekaba plywood than the poplar plywood values. It was shown that adding the alfa-x to urea formaldehyde decreased to a small extend the strength characteristics of plywood which is bonded with this resin.
2. Besides, there was a less extreme decrease in content of free formaldehyde. There were higher values of free formaldehyde in the ekaba plywood than the poplar plywood, and the free formaldehyde content value in both samples was reduced by adding Alfa-x to the adhesive.
3. The conclusion was that Alfa-x reducing formaldehyde emissions levels should be used preferably in building material because such emissions are highly important for the human health.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Murat ÖZALP: Performed the experiments and analyse the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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