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The barrier layer protecting wooden products against fire action with the use of component plywood
Part I Core material – plywood

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Abstract: *The barrier layer protecting wooden products against fire action with the use of component plywood Part I Core material – plywood*. Research on the barrier layer protecting wooden products against fire action with the use of component plywood are presented on the example of the composite plywood. The composite plywood consisting of: 3-layer protected against fire component plywood and 9-layer core plywood - beech UF-industrial, classic – not protected against fire (thickness 14.5 mm) was produced. Fire resistance of the component plywood was sufficient to protect core plywood against fire. The combustion index ranged from 0.68 to 0.75 and the flammability index oscillated between 0.06 and 0.07 which allows to classify composite plywood as a hardly flammable material acc. to PN-96/B-02874. Component plywood can be a semi-finished product useful for the production of fireproof wood- based materials.

Keywords: plywood, fire, barrier, protection, resin, MUF, adhesive

INTRODUCTION

Products made of wood and wood-based materials are now increasingly regarded as future-proof building materials due to the renewable nature of the raw material that is the basis for their production. Except for many proper features of these products as building materials, they are distinguished by their low weight, with at the same time high strength, low thermal conductivity, good insulting properties, high aesthetic values, etc. According to current standards (PN-EN ISO 1182), these materials as organic substances are classified as combustible ones. Although wood materials are relatively easily ignited and can spread fire quickly, wooden structures, especially with large cross-sections, can show high fire resistance. Therefore, without special treatments wood- based materials are mostly classified in terms of reaction to fire to class D, s1 - s3, d0 - d2 (as material with contribution to fire). In order to classify a wood-based material as building one with a lower susceptibility to fire such as class B - very little contribution to fire or class C - limited contribution to fire (PN-EN 13501-1), it is often used to protect this material with fire retardants (JÓŹWIAK and FOJUTOWSKI 2018, ÖSTMAN et al. 2017). According to another standard (PN-96/B-02874), the classes of materials such as non-flammable, hard flammable, easy flammable correspond to classes B, C and D (PN-EN 13501-1) respectively. The chemical flame retardants applied to the surfaces or inside of the wood / wood-based materials alter the course of the combustion process reducing the thermal effects of combustion (CZAPLICKA-KOLARZOWA et al. 2010, FOJUTOWSKI 2002, OINGWEN et al. 2009, TERZI et al. 2011). The use of such flame retardants to impregnate the veneers and the special method of gluing resulted in receiving a hard and even non-flammable plywood (JÓŹWIAK and FOJUTOWSKI 2019). The study investigates the effect of fire retardant treated plywood (component plywood) as a protective anti-fire agent for other wood-based materials on the example of not fire protected plywood.
The aim of the research was to determine the possibility of obtaining a non-flammable wood-based composite material by gluing it with fire-protected plywood.

MATERIALS AND METHODS

MUF Resin. We applied MUF resins condensed on the lab scale for the molar ratio formaldehyde (F): melamine (M) : urea (U) like as 2.8:1.0:1:0 for film and adhesive and 3.8:1.0:1:0 only as adhesive. The condensation was a tree-step process carried out using the no-waste method, performed at temperature of 82± 2°C. Condensation was carried out to water tolerance in the range of 150÷120%. Polycondensate was not distilled. Details concerning the synthesis developed earlier (JÓŹWIAK 2011). Resins were stored at a temperature of 20 ± 2°C.

The basic physicochemical properties of the resin were determined using the following methodologies:

- apparent viscosity using Emil rotational viscometer in compliance with PN-92/C-89402,
- content of dry mass according to PN-EN 827 (weighed sample 2.0 ± 0.1 g were dried at a thermal chamber with natural air circulation at 120 ± 1 ° C during 120 ± 1 min),
- pH applying pH-meter with combined electrode according to PN-ISO 1148,
- gel time at 100°C according to BN 75/3537-01,
- free formaldehyde content by sulphite method according to PN-EN 1243.

Table 1. Physicochemical properties of adhesive MUF resin

Molar ratio	Apparent viscosity	Content of dry mass	pH	Gel time at 100°C	Free formaldehyde content
Mole	mPa·s	%	-	s	%
2.8:1.0:1.0	58	54.3	9,03	124	0,40
3.8:1.0:1.0	32	51,8	9,11	101	0,53

Component plywood. Veneer. Beech, alder and pine veneers of the dimensions of 300 × 300 × 1.8; 2.5 and 4.2 ± 0.1 mm, and MC = 6.5 ± 1.0%, were used.

Impregnation. The veneers were impregnated with a 30% water solution of fire-retardant compounds (based on ammonium phosphates and ammonium sulphate with the addition of biocides) using the cold bath method at 22 ± 2°C for 1-4 hours. They were conditioned in the laboratory conditions (22 ± 2°C, RH of 45 ± 5%) for the next 24 hours. Then they were dried at the temperature of 40°C for 120 minutes. And then again conditioned in the laboratory conditions.

Glue film/mixture. The hardener - 0.4% NH_4NO_3 – was added to MUF (molar ratio 2.8:1.0:1.0) resins. The glue mixture was applied on the one side or two sides of not impregnated or impregnated veneers with an adhesive roller in the amount of 180 g/m^2.

The pressing process to produce component plywood. After 30 min, 24h or 2 weeks of assembly time under the following conditions: temperature: 23 ± 2°C, relative humidity: 45 ± 5%, the sets of 3-layer plywood were assembled. Their structure was described in Tables 2 and 3. Then at temperature 125±2 °C for 1 min/1 mm of the thickness of plywood, under the pressure of 1.6 (alder) and 1.8 (beech) MPa, was pressed component plywood of veneers.

Core plywood. The 9-layer industrial beech UF plywood (thickness 14.5 mm) was used as a core plywood.

Composite plywood consisting of: 3-layer laboratory component plywood and core plywood were produced for four variants (see Table 3).

The hardener 1.2% NH_4NO_3 to MUF(molar ratio 3.8:1.0:1.0) resins added. The glue mixture was applied on the one side of component and core plywood with an adhesive roller in the amount of 100 g/m^2.

After 45 min of seasoning in normal conditions, at temperature 125±2°C for 1 min/1 mm of the thickness of component plywood, under the pressure of 1.2 MPa, was pressed composite plywood of core and component plywood.

Methods of testing. After 2 weeks of conditioning in normal conditions, the shear strength and wood failure of the glue line was determined acc. to EN-314-1, -2 standards (24 h soaking in water in temperature 20±3°C; test IF-20) and 5.1.3 (4 h boiling in water as well as 16 h drying in air at the temperature of 60±3°C and 4 h boiling in water and cooling in water to the temperature of 20±3°C; test AW-100), formaldehyde release by the flash WKI method acc. PN-EN 717-3 standard, and the degree of fire protection of the materials using the radiation method acc. PN-96/B-02874 standard.

RESULTS

Shear strength, wood failure and formaldehyde emission measured by the flash WKI method of three-layer component alder plywood obtained with used MUF resin and various parameters of assembly time of gluing and the number of impregnated veneers are presented in Table 2.

Table 2. Shear strength and wood failure and formaldehyde emission measured by the flask WKI method of three-layer component alder plywood obtained with used MUF resin and various parameters of the number of impregnated veneers and assembly time of gluing

Shear strength and wood failure after the tests acc. EN 314-1			Variants of gluing of 3-layer alder plywood									
			C1	C2	C3	I11	I21	I22	I31	I32	I33	I34
			The number of impregnated veneers									
Kind of tests	Basic statistic	Unit	-	-	-	1	2	2	3	3	3	3
p. 5.1.1. IF-20	x_{max}	MPa	2.55	2.70	3.28	1.90	2.82	2.71	3.43	2.84	2.74	2.93
	x_{avg}		**1.68**	**2.22**	**2.26**	**1.40**	**2.02**	**2.48**	**3.09**	**2.41**	**2.32**	**2.35**
	x_{min}		1.15	1.59	1.47	1.09	1.66	2.33	2.65	1.88	1.88	2.13
	δ_{n-1}		0.68	0.43	0.69	0.36	0.46	0.20	0.37	0.49	0.36	0.33
	N	%	40.6	19.4	30.7	25.8	22.9	8.1	12.0	20.2	15.4	14.2
	WF		62	96	94	96	40	100	96	100	84	70
p. 5.1.3. AW-100	x_{max}	MPa	1.43	2.81	2.57	1.98	2.09	2.10	1.82	1.98	1.85	2.05
	x_{avg}		**1.01**	**1.80**	**1.64**	**1.66**	**1.58**	**1.65**	**1.44**	**1.54**	**1.47**	**1.79**
	x_{min}		0.70	1.29	1.00	1.25	1.05	1.40	1.26	1.00	1.05	1.41
	δ_{n-1}		0.26	0.24	0.39	0.32	0.33	0.33	0.21	0.42	0.29	0.26
	N	%	26.0	13.5	23.5	19.1	20.7	20.3	14.7	27.5	19.9	14.7
	WF		67	98	96	18	6	61	21	62	68	51
Formaldehyde emission measured by the flask WKI method acc. to PN-EN 717-3												
F_v	mg CH_2O/100g dry mass of plywood		**6.63**	**6.00**	**6.20**	**1.11**	**0.27**	**0.44**	**0.13**	**0.10**	**0.11**	**0.12**
Moisture content	%		5.25	5.75	6.35	6.30	5.25	5.90	6.10	6.60	6.70	6.00

x_{max} - maximum, avg -average , x_{min} - minimum, δ_{n-1} – standard deviation; ν – variation coefficient; WF – wood failure , F_v- flash value

The method of bonding:

10 variants of various combinations with the use of liquid adhesive MUF resin (2.8:1.0:1.0) - assembly time of gluing 45 min **(k);** and/or glue layer seasoned in laboratory room conditions for the period of: 24 h **(b)** and/ or about 2 weeks **(B)** on alder 1.8 mm thickness veneer (MC 6.2±0.2%):

not impregnated **(ol)**, or impregnated **(ol (i)) –** amount of retardant based on mm of veneer thickness 90 $g \cdot mm^{-1}$,

Construction of plywood / amount of impregnated veneers

control plywood :(C1) ol-[**k**]-ol-[**k**-ol ; (C2) ol-[**b**-ol-**b**]-ol; (C3) ol-[**b**]-[**b**-ol-**b**]-[**b**-ol

1 veneer (I11) ol-[**b**-ol(i)-**b**]-ol ;

2 veneers (I21) ol(i)-[**b**-ol-**b**]-ol(i); (I22) ol(i)[**B**]-[**b**-ol-**b**]-[**B**ol(i);

3 veneers (I31) ol(i)-[**k**]-[**b**-ol(i)-**b**]-[**k**-ol(i); (I32) ol(i)-[**b**]-[**b**-ol(i)-**b**]-[**b**-ol(i) ;

(I33) ol(i)-[**b**]-[**B**-ol(i)-**B**]-[**b**-ol(i); (I34) ol(i)-[**B**]-[**B**-ol(i)-**B**]-[**B**-ol(i)

The component plywood fulfilled the requirements of EN-314-02 standard in terms of shear strength and water resistance of the adhesive glue lines, regardless of the number of impregnated veneers (1-3), method of gluing (liquid MUF resin; glue layer) and assembly time of gluing (45 min; 24 h; 2 week). The component plywood was characterised by much lower formaldehyde emission at the level obtained for raw alder wood.

Table 3. Combustion and flammability indexes of composite plywood consisting of 3-layer component plywood and industrial 9-layer beech core plywood (thickness 14.5 mm)

Tested property	Unit	Properties of component plywood			
Variants	-	S3	S2	S1	Control
Construction of component plywood	-	ol-so-ol	bk-bk-bk	ol-ol-ol	ol-ol-ol
Number of impregnated veneers		3	3	3	-
Thickness of veneers	mm	1.8-2.5-1.8	2.5-2.5-2.5	1.8-4.2-1.8	1.8-1.8-1.8
Thickness of component plywood	mm	5.9	7.3	7.7	5.2
Amount of retardant	$g \cdot mm^{-1}$ of veneer	92	96	110	-
Core plywood 9-layer beech, UF resin, thickness 14.5 mm					
Combustion and flammability indexes of composite plywood					
Max. temp. of combustion products	°C	50.0	51.2	48.4	68.5
Time to reach of max. temperature	s	1190	1195	1135	1200
Area F	°C·s	5434	4848	4890	27627
Combustion index	-	0.75	0.67	0.68	3.84
Ignition time of the lower surface	s	895	1049	966	38
Flammability index	-	0.07	0.06	0.07	1.76
Moisture content	%	8.3	8.2	8.1	9.2
Thickness of composite plywood	mm	20.3	21.7	22.0	19.2

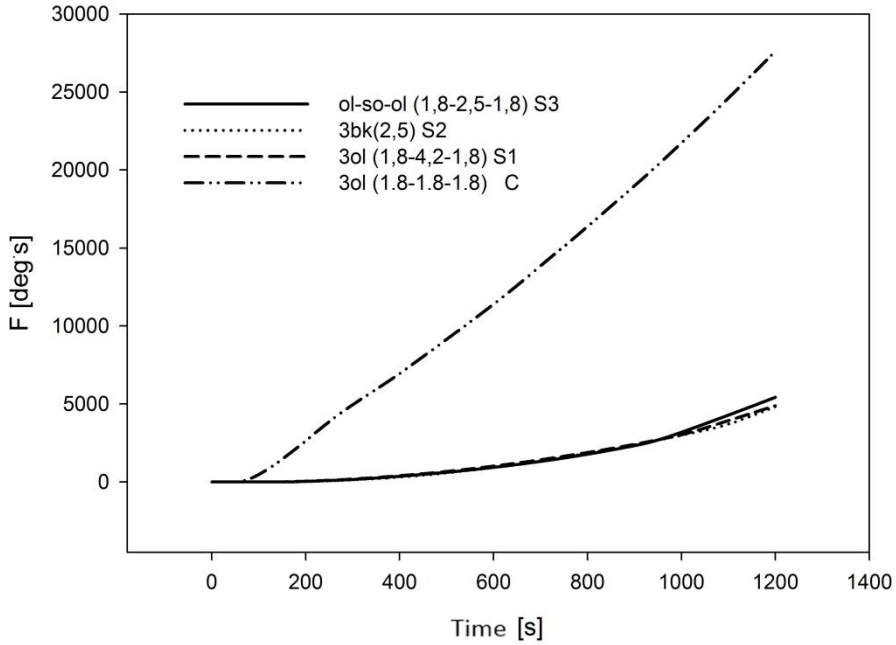

Figure 1. Effect of type and thickness of composite plywood consisting of 3-layer component plywood and industrial 9-layer beech plywood (thickness 14.5 mm) on the amount of heat generated during combustion and thermal decomposition in the test chamber (area F) according to radiation method according to PN-96/B-02874; legend see Table 3

The structure and fire properties of composite plywood obtained from component plywood and base plywood are presented in Table 3.
The effect of type and the thickness of the composite plywood consisting of 3-layer component plywood and industrial 9-layer beech plywood (thickness 14.5 mm) on the amount of heat generated during combustion and thermal decomposition in the test chamber (area F) according to radiation method.
The combustion index ranged from 0.68 to 0.75 and the flammability index oscillated between 0.06 and 0.07: therefore, the composite plywood was classified as a hardly flammable material acc. to PN-96/B-02874.

CONCLUSIONS

The protection of wood products in the form of component plywood are sufficiently fire protection methods. The combustion index is in the range from 0.68 to 0.75 and the flammability index oscillates only in the range from 0.06 to 0.07. The component plywood can be a semi-finished product useful for the production wood composite materials that are protected against fire.

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Streszczenie: *Warstwa barierowa zabezpieczająca wyroby drzewne przed działaniem ognia przy zastosowaniu sklejki komponentowej. Część I. Materiał rdzeniowy – sklejka.* Na przykładzie sklejki kompozytowej przedstawiono badania efektywności warstwy barierowej zabezpieczającej wyroby drzewne przed działaniem ognia z użyciem sklejki komponentowej. Wyprodukowano sklejkę kompozytową składającą się z: 3-warstwowej sklejki komponentowej zabezpieczonej przeciwogniowo oraz 9-warstwowej sklejki rdzeniowej - bukowej UF - przemysłowej, klasycznej - niezabezpieczonej przeciwogniowo (grubość 14.5 mm) . Zabezpieczenie przeciwogniowe sklejki komponentowej okazało się wystarczające do ochrony sklejki rdzeniowej przed ogniem. Wskaźnik spalania sklejki kompozytowej wahał się od 0.68 do 0.75, a wskaźnik palności wahał się w granicach 0.06 – 0.07, co pozwala zaklasyfikować sklejkę kompozytową, jako materiał trudno zapalny wg PN-96 / B-02874. Sklejka komponentowa może być półfabrykatem przydatnym do produkcji trudno zapalnych materiałów drewnopochodnych.

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