

REDUCTION OF FORMALDEHYDE EMISSION FROM WOOD-BASED PANELS BY MODIFICATION OF UF ADHESIVES WITH NATURAL BIOPOLYMERS

Ján Matyašovský¹, Ján Sedliacik², Peter Jurkovič¹, Peter Duchovič¹, Igor Novák³

¹VIPO a.s., Partizánske, Slovakia,

²Technical University in Zvolen, Zvolen, Slovakia,

³Slovak Academy of Sciences, Bratislava, Slovakia

e-mail: jmatyasovsky@vipo.sk; sedliacik@tuzvo.sk; igor.novak@savba.sk

ABSTRACT

At present, polycondensation urea-formaldehyde (UF) resins are the most widely used wood gluing adhesives, but their main disadvantage is their low resistance to water and moisture, which causes the subsequent release of formaldehyde emissions from finished products. The aim of the study was to reduce the release of formaldehyde from wood materials by developing and testing new, more effective modifiers that bind formaldehyde or form more stable methylene bonds during polycondensation. Research was focused on the biopolymer collagen and keratin. For this study collagen samples were modified with hardener RODA M 210 (manufacturer Duslo Šaľa) and sulphur additive. From biopolymer keratin, which can be found in hair, feather, wool, nails, hoofs, horns, etc., were prepared samples by thermal heating during for 1 hour at various temperatures from 150°C to 197°C. XPS Ray photoelectron spectroscopy analyse was used to identify changes in their surface chemical structure. The XPS spectrum of keratin samples has been shown to depend on the temperature of their thermal degradation, with the total amount of carbon, nitrogen and sulphur increasing with increasing temperature. For sulphur, the total amount of its reduced form expressed as sulphide also increases, while the total amount of oxygen decreases with increasing temperature. Technical applications have focused on the application of keratin samples to modify mixtures of UF resins to reduce the release of formaldehyde from glued wood-based panels. Formaldehyde emissions were assessed from five-layer plywood according to EN ISO 12460-4. Measured values of extinctions of tested samples confirmed the decrease of formaldehyde emissions for each concentration of collagen and keratin samples in comparison with the reference sample.

Key words: UF adhesive, modifier, keratin, collagen, UF resin, plywood, gluing, formaldehyde emission.

INTRODUCTION

In woodworking industry, at present, polycondensation urea-formaldehyde (UF) resins are the most used adhesives for wood-based panels. Annual European production of UF adhesives achieves about 4.8 million tons, of which 60% is consumed for production of particleboard

30% for production of medium density fibreboards (MDF), and 10 % for adhesive bonding in production of furniture, interior doors, and plywood (Maminski *et al.* 2006).

Glutaraldehyde (GA) is chemical matter, which is often tested for modification of hardeners, there is the assumption, which is completely cross-linked into the structure of the adhesive. Maminski *et al.* 2006 investigated melamine-urea-formaldehyde (MUF) adhesive, they added GA into the hardener in form of 50% water solution. Shear strength of birch samples glued with modified adhesive was significantly higher in comparison with the reference sample. Also, there is a direct bond of GA with chemical compounds

of wood, what significantly increases the strength of glued joint. The percent of fibre destruction was much higher, modified adhesive proved stronger interaction adhesive-wood.

Their wide utilisation is allowed by their relative low price, high reactivity, availability of raw material and easy applicability, after hardening they provide transparent, but fragile bond. UF adhesives are thermo-reactive resins hardening in wide interval of temperatures with short time of condensation and they are resistant against micro-organisms. A major disadvantage is their low water and moisture resistance and consequent toxicity caused by the hydrolysis and release of formaldehyde (fd) from finished products. Much contemporary research describes emission of formaldehyde mainly from three sources: the residual formaldehyde present in the resin, formaldehyde formed by the polycondensation reaction between hydroxymethyl groups and formaldehyde released by hydrolytic degradation of hardened resin, especially under conditions of increased humidity and increased temperature.

Formaldehyde adversely affects the respiratory system, eyes, skin, genetic material, reproductive organs, and has a strong effect on the central nervous system (Příhoda 1988).

The research of modification of adhesives is aimed on utilisation of products, which are easily accessible, and their application save the costs for resin production. On the market, there is large number of biopolymers, which as secondary raw material can be used for modification of adhesives with the aim to keep and/or increase the quality of adhesives and glued joints. Leather and food industry produces amount of different biopolymer waste, which pollutes the environment (Pünterer 1995, Buljan *et al.* 1997, Matyašovský *et al.* 2011).

The shear strength of glued joint directly depends on the resistance against humidity. Suitable modification of adhesive mixtures can reach better cross-linking of the structure of hardened adhesive, increase of durable chemical bonds and lowering of the hydrolysis of adhesive. The research aimed not only on the study of properties of wood and adhesives, but as glued products are also the subject exposed to the environment in which they are located, and to study their interactions (Šmidriaková *et al.* 2011).

Langmaier *et al.* 2004 in his experiments used hydrolysate of chromium waste from leather industry obtained by enzymatic hydrolysis. Non-isothermal thermogravimetric method (TGA) was used at investigation of condensation reactions of dimethylol-urea (DMU) and its mixtures with different weight content of urea, hydrolysate, or acid hardener.

Thermo-oxidative stability of different materials and biopolymers was tested by differential scanning calorimetry (DSC). The method is based on determination of the end of induction period, or the beginning of the main oxidation process (Šimon *et al.* 2001, Šimon *et al.* 2006).

Literary research and practical requirements indicated the existence of a potential to apply modifiers of protein hydrolysates for adjusting parameters of wood adhesives, particularly polycondensation UF resins. Biologically active natural products are suitable to be used for new applications in the technology of polycondensation adhesives. (Ružiak *et al.* 2017, Sedliačik *et al.* 2011, Zhao *et al.* 2012).

Collagen and keratin are renewable materials, and their sources are almost unlimited. Therefore, there is an effort to constantly improve existing products and find new options for their application and processing (Matyašovský *et al.* 2014).

Experimental research was aimed on preparation of adhesive mixtures and testing their influence on formaldehyde emission and strength of glued joint. The aim of the study was to reduce the release of formaldehyde from wood materials by developing and testing new more effective keratin-based environmental modifiers that bind formaldehyde and form more stable methylene bonds and their effect on the bond strength of wood-based panels.

EXPERIMENTAL METHODS

MATERIALS AND CHEMICALS

Collagen of type I was prepared from pig skins by hydrolysis of fibril structure through the application of proteolytic enzymes, alkalis, acids or lyotropic agent. This type of collagen was applied to experimentally test the reduction of formaldehyde emissions from UF cured adhesive mixtures. Concentrating and subsequent drying can extend stability of biopolymer for more than 12 months. Chemical and physical parameters of dried collagen are described in Table 1.

Table 1: Physical and chemical parameters of dry collagen No.1 hydrolysate

Total nitrogen	14.9%
Size of particles	60 Mesh or 0.25 mm
Bloom at concentration 6.67% and temperature 10 °C	191
Viscosity at concentration 6.67% and temperature 60 °C	2.6 mPa.s
pH	5.2
Dry content matter	90.8%
Ash	< 2%

To increase the efficiency, collagen was modified with hardener RODA M 20 (manufacturer Duslo Šaľa, Slovakia), with the following parameters: pH = 7.4, total nitrogen as N – wt. 21.5 % and amide nitrogen as NH₂ – mass 4.5 and sulphur additive.

In the experimental work, UF glue KRONORES CB 1639F was applied and hardener DAM 390 containing 30% nitrogen with a ratio of ammonium, nitrate, and amide nitrogen of 1: 1: 2 = (7.5%: 7.5%: 15%) were applied as a standard, (manufactured by Duslo Šaľa – Slovakia). Formaldehyde emissions in the bonded material were determined by the desiccator method according to EN ISO 12460-4 Wood-based panels. Determination of formaldehyde release. Part 4: Desiccator method.

Adhesive mixtures for modification UF resin were prepared according to following scheme:

Reference: 100% KRONORES CB 1639F + 20% technical flour+ 5% DAM 390 hardener,

Sample No.1: 100% KRONORES CB 1639F + 20% technical flour + (0.0; 0.2; 0.5; 1.0; 3.0) % collagen No.1 prepared from pig skin + 5% RODA M 210 hardener,

Sample No.2: 100% KRONORES CB 1639F + 20% technical flour + hardener 5% RODA M 210 modified with (0.0; 0.2; 0.5; 1.0; 3.0) % collagen No.1 prepared from pig skin,

Sample No.3: 100% KRONORES CB 1639F + 20% technical flour + hardener 5% RODA M 210 + modified 0,5% sulphur additive and subsequently modified (0.0; 0.2; 0.5; 1.0; 3.0) % collagen No.1 prepared from pig skin.

Modification of urea-formaldehyde adhesives was also solved by preparation and application of four samples of keratin, which were prepared from crushed horn by its thermal degradation at temperatures from 150 °C

to 197°C for one hour. The samples were characterized by XPS and FTIR-ATR spectroscopy and technical applications were focused on their application to urea-formaldehyde (UF) resins in order to reduce formaldehyde emissions from glued wood-based boards while maintaining the quality of the glued joint. Formaldehyde emission was tested according EN ISO 12460-4 and bonding quality according to standards EN 314-1 and EN 314-2.

Description and labelling of prepared samples No:

1. Keratin K-1 (a) – prepared by thermal degradation for 1 hour at 150°C,
2. Keratin K-2 (b) – prepared by thermal degradation for 1 hour at 170°C,
3. Keratin K-3 (c) – prepared by thermal degradation for 1 hour at 190°C,
4. Keratin K-4 (d) – prepared by thermal degradation for 1 hour at 197°C.

After modification, the samples were crushed in a ball mill, homogenized by sieving, and their chemical composition was determined by X-ray photoelectron spectroscopy and FTIR-ATR spectroscopy.

Adhesive mixtures for modification UF resin were prepared according to following scheme:

0: 100% UF adhesive – KRONORES CB 1639F + 20% technical flour + 5% DAM 390 hardener – Reference,

1-5: 100% UF adhesive – KRONORES CB 1639F + 19.5% technical flour + 0.5% – Keratins (K-1(a) K-2(b) K-3(c) K-4(d)), modifications by thermal degradation at (150; 170; 190; 197)°C + 5% DAM 390,

6-10: 100% UF adhesive + 19.0% technical flour + 1.0% – Keratins (K-1(a) K-2(b) K-3(c)

K-4(d)), modifications by thermal degradation at (150; 170; 190; 197) °C + 5% DAM 390,

11-12: 100% UF adhesive + 17.0% technical flour + 3.0% – Keratins (K-1(a) K-2(b) K-3(c)

K-4(d)), modifications by thermal degradation at (150; 170; 190; 197) °C + 5% DAM 390.

MEASUREMENTS METHODS

X-Ray photoelectron spectroscopy

XPS signals were recorded following a previously described procedure using a Thermo Scientific K-Alpha XPS system (Thermo Fisher Scientific, UK) equipped with a micro-focused, monochromatic Al K α X-ray source (1486.6 eV). An X-ray beam of 400 μm size was used at 6 mA \times 12 kV. The spectra were acquired in the constant analyser energy mode with pass energy of 200 eV for the survey. Narrow regions were collected using the snapshot acquisition mode (150 eV pass energy), enabling rapid collection of data (5 s per region). A version 5.988 of the *Thermo Scientific Avantage* software was used for the data acquisition and processing. Spectral calibration was determined using the automated calibration routine with the use of internal standards of Au, Ag and Cu provided with the K-Alpha system.

ATR-FTIR spectroscopy measurements

FTIR-ATR (Fourier Transform Infrared Attenuated Total Reflectance Spectroscopy) was used to investigate the surface chemical composition. Spectra were recorded on a NICOLET 8700™ by ThermoScientific instrument (Madison, WI, USA) in the middle infrared region in transmission mode. KBr pellet technique was used to expand the examined spectral region below 650 cm^{-1} circumvent the optical material used in ATR measurements (germanium crystal) limit. This process should allow detection of the sulfidic vibrations, which occur in region between 700 cm^{-1} – 500 cm^{-1} . Transparent tablets were

prepared from the samples by pressing individual substances up to 2 mg into KBr.

Plywood strength testing

Quality of gluing was tested according to standards EN 314-1 and EN 314-2. Three-layer plywood of birch (*Betula pendula*) veneer was prepared for determination of physical and mechanical properties at following conditions: pressing (laboratory hydraulic press FONTIJNE) pressure 1.8 MPa, temperature 105°C, time 5 resp. 6 min. Plywood were conditioned at the temperature of $20 \pm 2^\circ\text{C}$ and relative humidity $65 \pm 5\%$. Tested pieces were pre-treated for the class 1:

- immersion in water 20°C for 24 hours,
- constant rate loading,
- disruption after 30 ± 10 seconds,
- accuracy of 1 N.

Formaldehyde emissions

Formaldehyde emissions from five-layer plywood were tested according to the

test method EN ISO 12460-4 according to following conditions:

- volume of desiccator: $9\text{--}11\text{ dm}^3$,
- loading coefficient: 1800 cm^2 ,
- temperature of $20 \pm 0.5^\circ\text{C}$,
- test duration 24 h,

The concentration of formaldehyde absorbed in distilled water was evaluated by acetyl-acetone method with spectrophotometric evaluation using the ultraviolet spectrophotometer UviLine SI 5000 at 412 nm wavelength.

RESULTS AND DISCUSSION

Influence testing of samples of UF adhesive mixtures with collagen No. 1 and its modifications with concentrations (0.0, 0.2, 0.5, 1.0, 3.0%) calculated on the weight of the adhesive for the life of the adhesive mixtures is described in Table 2.

Table 2: Influence of samples No. 1,2,3 for the lifetime of UF adhesive mixtures at room temperature

Sample No.	Life of the adhesive mixture at 20°C
0 – Reference	> 1 week
1	> 1 week
2	> 1 week
3	> 1 week

All adhesive mixtures have a comparable service life to the reference UF adhesive sample.

Results of measurements of the effect of the amount of collagen No. 1 and its modifi-

cation to the condensation time of the UF adhesive mixture are shown graphically in Fig. 1. The condensation time determined in a test tube at a temperature of 100°C was calculated from an average of 5 measurements.

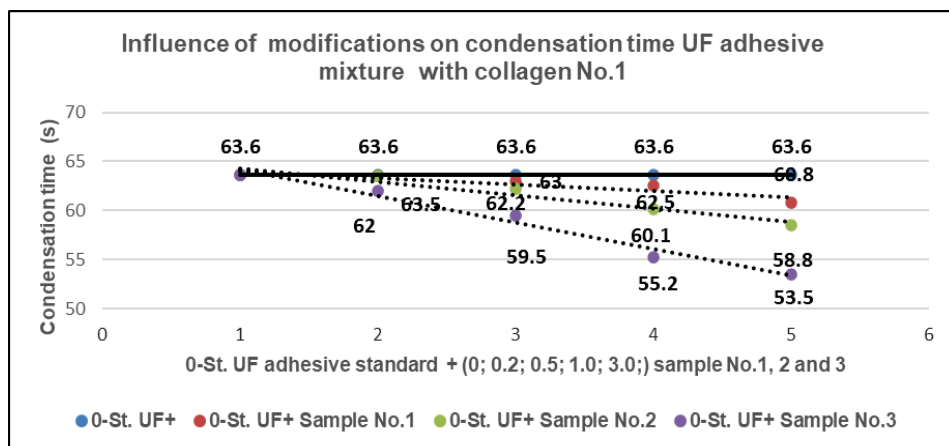


Figure 1: Influence of samples No. 1, 2, 3 for the condensation time of UF adhesive mixtures

The measured data show that the condensation time of UF adhesives is affected by the modification and concentration of collagen No.1 in the adhesive mixture. Sample No. 3 collagen No. 1 modified with hardener RODA M and sulphur additive most significantly accelerates the condensation time, while this effect increases with its increasing concentration from the value of the reference sample 63.6 to 53.5 s.

Testing the effect of collagen No.1 and its modifications on formaldehyde emissions of UF adhesive mixtures: UF adhesive KRFORES CB 1639F and its modifications were condensed at 90 °C for 45 minutes. The results of measurements of the effect of UF adhesive modifications on the free formaldehyde content in % are shown graphically in Fig. 2.

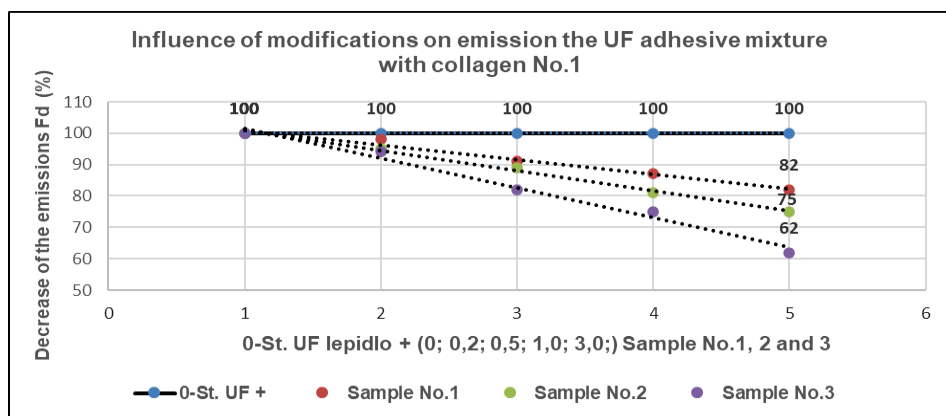


Figure 2: Impact of samples No. 1, 2 and 3 on formaldehyde emissions of UF adhesive

The measured values show that collagen and its modifications are suitable for reducing formaldehyde emissions in cured UF adhesive mixtures. Sample No. 3 modified with hardener RODA M 20 and sulphur additive most significantly reduces formaldehyde

emissions, while this effect increases with its increasing concentration. Formaldehyde emissions were tested by the desiccator method according to EN ISO 12460-4, while a reduction in emissions of 38% was achieved by comparison with a reference

sample – (0- St. UF adhesive KRONORES CB 1639F + 20% technical flour + 5% DAM 390).

Testing the effect of collagen No.1 and its modifications on the viscosity of UF ad-

hesive mixtures: The results of the measurements of the effect of the modifications of the UF adhesive on the viscosity of the UF adhesive mixture are shown graphically in Fig. 3.

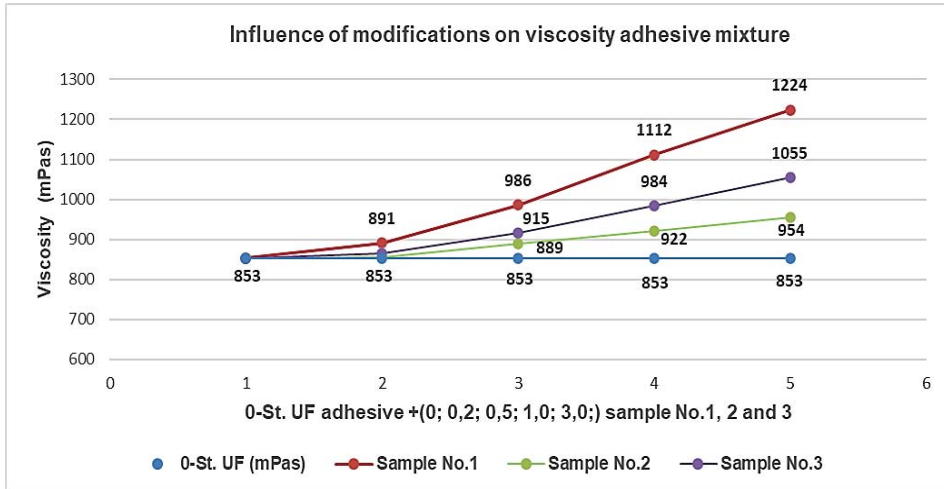


Figure 3: Influence of collagen modifications on the viscosity of UF adhesive mixtures

The measured values indicate that collagen is a suitable modifier to adjust the viscosity. Collagen No. 1 prepared from pork skins further unmodified most significantly increases the viscosity of the UF adhesive composition, this effect increasing with its increasing concentration from the value of the reference sample 853 [mPa.s] to 1224 [mPa.s] at its 3% concentration. The measured values show that collagen and its modifications are suitable. UF adhesive viscosity modifiers are suitable

X-Ray photoelectron spectroscopy (XPS) was used for qualitative and quantitative determination of basic elements prepared samples of biopolymers keratin and the results are summarized as follows: overall carbon (C1s signal at ~ 285 eV), oxygen (O1s signal at ~ 532 eV), nitrogen (N1s signal at ~ 400 eV), natrium (Na1s signal at ~ 1072 eV), chlorine (Cl2p signal at ~ 198 eV), and sulphur as C-S (S2p signal at ~ 163 eV) and SO3 (S2p signal at ~ 168 eV). Analysis of sample surfaces determined by X-Ray photoelectron spectroscopy can be seen on the Table 3.

Table 3: Apparent surface chemical composition samples of keratin as determined by XPS

Surface chemical composition of samples prepared from keratin [%]						
Sample No.	C1s	O1s	N1s	S2p	Sulphide (C-S)	Oxide (SO ₂)
K-1 ^(a)	65.1	20.7	11.5	1.2	54.6	44.5
K-2 ^(b)	66.5	19.3	11.7	1.2	61.3	38.7
K 3 ^(c)	68.0	17.2	12.1	1.3	67.6	32.4
K-4 ^(d)	69.7	13.4	14.1	1.4	76.2	23.8

The differences between the spectra of prepared samples are visible mainly in the

amount of sulphur and in the ratio of the reduced state C-S (signal S2p at -163 eV) and

the oxidized state SO₂ (signal S2p at 168 eV).

Analyses have confirmed that the XPS spectrum of keratin samples depends on the temperature of their thermal degradation, with the total amount of carbon, nitrogen and sulphur increasing with increasing temperature. In the case of sulphur, the total amount

of its reduced form, expressed as sulphide, also increases, while the total amount of oxygen decreases with increasing temperature. Examination of the surface chemical composition of thermally treated samples of keratin powders prepared from crushed horn was further characterized by the FTIRTM Spectrometer NICOLET is shown in Table 4. and graphically shown in Fig. 4.

Table 4: Comparison of positions of maximum wavelengths for the area of valence vibrations

Sample	-CO-NH	-CH	Amide I	Amide II	Oxides (SO ₂)	Sulfide (SH)	di-Sulfide (SH)
Keratin-1 ^(a)	3316	2960	1654	1514	1169	866	605
Keratin-2 ^(b)	3391	2960	1652	1516	1079	859	562
Keratin-3 ^(c)	3302	2960	1654	1516	1170	858	699/613
Keratin-4 ^(d)	3302	2960	1656	1518	1170	854	611

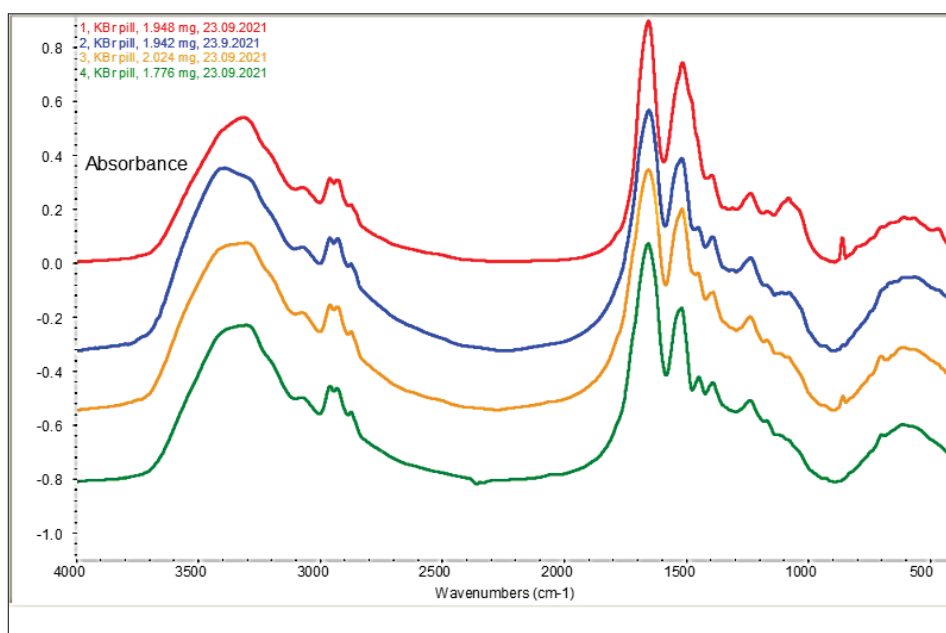


Figure 4: FTIR-ATR spectra samples of various temperature-treated crushed horns

The band approximately with a maximum at 1170 cm⁻¹ is characteristic for sulphur oxides (SO₂) stretch vibration.

The band in the spectral range of 500–700 cm⁻¹ can be assigned to the alkyl- and dialkyl sulphide (C-S) stretch vibrations.

Keratin samples No. K-1 (a) K-2 (b) K-3 (c) K-4 (d) were tested to determine their influence on release of formaldehyde and quality of gluing from wood-based panel bonded with UF resins. Results evaluation of the influence of modifications on the release formaldehyde and shear strength of the plywood test pieces are shown in Figs. 5 and 6.

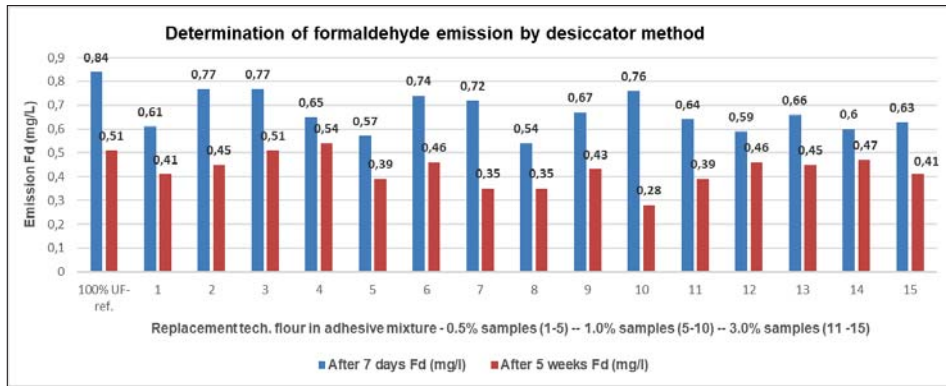


Figure 5: Results of formaldehyde emission by desiccator method [mg/L]

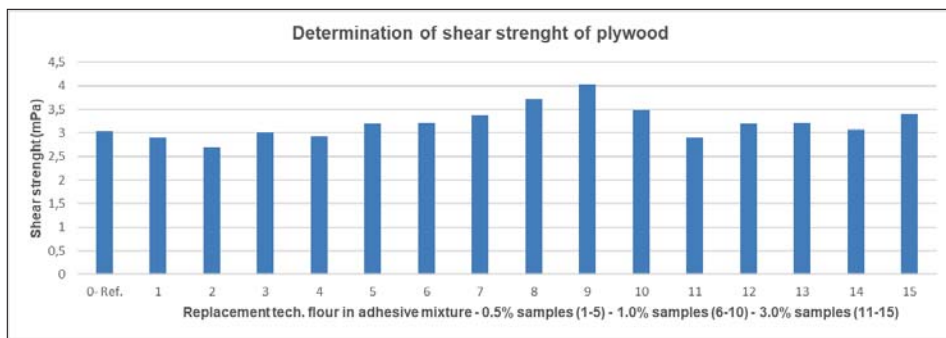


Figure 6: Shear strength of the plywood [MPa]

The measured values of formaldehyde emissions of the tested samples of UF adhesive mixtures are graphically shown in the figure and confirmed the decrease of formaldehyde emissions for all keratin additives compared to the reference one. The most significant reduction in formaldehyde emissions of up to 35% determined after 7 days was achieved with the modification of sample No. 8 – prepared by application of 1.0% concentration (keratin modified at 180°C for 1 hour). The most significant reduction in formaldehyde emissions of up to 45% determined after 5 weeks was achieved with the modification of sample No.10 – prepared by applying a 1.0% concentration of keratin (modified at 197°C for 1 hour).

Bonding quality was tested according to bonding class 1. The highest shear strength of

4.0 MPa was achieved in sample No. 9 – prepared by applying 1.0% concentration (keratin modified at 190°C for 1 hour).

CONCLUSIONS

Modern research and development in the field of wood polycondensation adhesives is aimed at finding new materials and technologies, or at targeted modifications of existing technologies. The stability of amino plastic adhesives and the problem of toxicity of UF adhesives have been addressed by the addition of biopolymers that bind the released formaldehyde or form more stable methylene bonds more resistant to back hydrolysis of the adhesive, thus achieving reduced formaldehyde emissions. The aim of this study was focused on the biopolymer collagen and keratin. Testing the effect of collagen – type 1, prepared from pig skin and its subsequent

modifications to the service life, condensation time, formaldehyde emissions and viscosity of UF adhesive compositions have confirmed that collagen is a suitable modifier of these properties of UF adhesive compositions.

The measured values of formaldehyde emissions of the tested samples of UF adhesives confirmed the decrease of formaldehyde emissions for all keratin additives compared to the reference sample. Bonding quality was tested according to bonding class 1. The European standard EN 314-2 requires a value of the shear strength of the glued joint of 1.0 MPa and all prepared samples far exceed this required minimum. The tested plywood boards were suitable for gluing class 1 – use in a normal indoor environment.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under the contracts No. APVV-14-0506, APVV-15-0124, APVV-18-0378, APVV-19-0269 and VEGA 1/0264/22.

REFERENCES

- BEKHTA P., SEDLIAČIK J., KAČÍK F., NOSHCHENKO G., KLEINOVÁ A. 2019. Lignocellulosic waste fibers and their application as a component of urea-formaldehyde adhesive composition in the manufacture of plywood. *European Journal of Wood and Wood Products*, 77, 4: 495–508.
- BULJAN J., REICH G., LUDVIK J. 1997. Mass Balance in Leather Processing. In: *Centenary Congress of the IULCS*: 138–156.
- LANGMAIER F., ŠIVAROVÁ J., KOLOMAZNIK K., MLÁDEK M. 2004. Curing of urea-formaldehyde adhesives with collagen type hydrolysates under acid condition. *Journal of Thermal Analysis and Calorimetry*, 76: 1015–1023.
- MAMIŃSKI, M., PAWLICKI J., PARZUCHOWSKI P. 2006. Improved water resistance and adhesive performance of a commercial UF resin blended with glutaraldehyde. *The Journal of Adhesion*, 82, 6: 629–641.
- MATYAŠOVSKÝ J., SEDLIAČIK J., JURKOVIČ P., KOPNÝ J., DUCHOVIČ P. 2011. De-chroming of chromium shavings without oxidation to hazardous Cr6+. *The Journal of the American Leather Chemists Association*, 106, 1: 8–17.
- MATYAŠOVSKÝ J., SEDLIAČIK J., MATYAŠOVSKÝ J.JR., JURKOVIČ P., DUCHOVIČ P. 2014. Collagen and keratin colloid systems with a multifunctional effect for cosmetic and technical applications. *The Journal of the American Leather Chemists Association*, 109, 9: 284–295.
- MATYAŠOVSKÝ J., SEDLIAČIK J., ŠIMON P., NOVÁK I., KRYSOFLAK T., JURKOVIČ P., DUCHOVIČ P., SEDLIAČIKOVÁ M., CIBULKOVÁ Z., MIČUŠÍK M., KLEINOVÁ A. 2019. Antioxidant activity of keratin hydrolysates studied by DSC. *The Journal of the American Leather Chemists Association*, 114, 1: 20–28.
- PŘÍHODA P. 1988. Hygienické aspekty problematiky formaldehydu unikajícího z výrobků dřevozpracujícího průmyslu. In: *Syntema – Chemizace dřeva průmyslu. Dom techniky ČSVTS Brno*: 45–53.
- PÜNTERER A. 1995. The Ecological Challenge of Producing Leather. *The Journal of the American Leather Chemists Association*, 90: 206–215.
- RUŽIAK I., IGAZ R., KRÍŠŤÁK L., RÉH R., MITTERPACH J., OČKAJOVÁ A., KUČERKA M. 2017. Influence of Urea formaldehyde Adhesive Modification with Beech Bark on Chosen Properties of Plywood. *Bio Resources*, 12, 2: 3250–3264.
- SEDLIAČIK J., MATYAŠOVSKÝ J., ŠMIDRIAKOVÁ M., SEDLIAČIKOVÁ M., JURKOVIČ P. 2011. Application of collagen colloid from chrome shavings for innovative polycondensation adhesives. *The Journal of the American Leather Chemists Association*, 106, 11: 332–340.
- ŠIMON P. 2006. Induction periods – Theory and applications. *Journal of Thermal Analysis and Calorimetry*, 84, 1: 263–270.
- ŠIMON P., KOLMAN L. 2001. DSC study of oxidation induction periods. *Journal of Thermal Analysis and Calorimetry*, 64: 813–820.
- ŠMIDRIAKOVÁ M., SEDLIAČIK J., MATYAŠOVSKÝ J. 2011. Prírodné polyméry na báze modifikovaného kolagénu ako čiastočná náhrada UF lepidla. In *Adhesives in Woodworking Industry*, Zvolen: 14–20.
- ZHAO Y., DING Z. 2012. The Application of Keratin in the Field of Wood Adhesive. *World Automation Congress Proceedings, Puerto Vallarta; Mexico*.



UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY



INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2023

INNO vol. XII Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Science Journal
Vol. 12/ p. 1–80
Sofia 1/2023

ISSN 1314-6149
e-ISSN 2367-6663

Edition of
FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

SCIENTIFIC EDITORIAL BOARD

Alfred Teischinger, PhD (Austria)	Marius Barbu, PhD (Romania)
Alexander Petutschning, PhD (Austria)	Muhammad Adly Rahandi Lubis, PhD (Indonesia)
Anna Danihelová, PhD (Slovakia)	Nencho Deliiski, DSc (Bulgaria)
Antonios Papadopoulos, PhD (Greece)	Neno Tritchov, PhD (Bulgaria)
Asia Marinova, PhD (Bulgaria)	Pavlin Vitchev, PhD (Bulgaria)
Biborka Bartha, PhD (Romania)	Pavlo Bekhta, PhD (Ukraine)
Bojidar Dinkov, PhD (Bulgaria)	Petar Antov, PhD (Bulgaria)
Danijela Domljan, PhD (Croatia)	Regina Raycheva, PhD (Bulgaria)
Desislava Angelova, PhD (Bulgaria)	Roman Réh, PhD (Slovakia)
Derya Ustaömer, PhD (Turkey)	Ružica Beljo Lučić, PhD (Croatia)
George Mantanis, PhD (Greece)	Silvana Prekrat, PhD (Croatia)
Ivica Grbac, PhD (Croatia)	Štefan Barčík, PhD (Slovakia)
Ivo Valchev, PhD (Bulgaria)	Svetoslav Anev, PhD (Bulgaria)
Ján Sedliačik, PhD (Slovakia)	Valentin Shalaev, PhD (Russia)
Julia Mihajlova, PhD (Bulgaria)	Vasiliki Kamperidou (Greece)
Hubert Paluš, PhD (Slovakia)	Vesselin Brezin, PhD (Bulgaria)
Hülya Kalaycioğlu, PhD (Turkey)	Victor Savov, PhD (Bulgaria)
Ladislav Dzurenda, PhD (Slovakia)	Vladimir Koljozov, PhD (Macedonia)
Luboš Krišták, PhD (Slovakia)	Zhivko Gochev, PhD (Bulgaria)

EDITORIAL BOARD

N. Trichkov, PhD – Editor in Chief	V. Savov, PhD
D. Angelova, PhD – Co-editor	P. Vitchev, PhD
N. Minkovski, PhD	

Cover Design: **DESI SLAVA ANGELOVA**

Printed by: **INTEL ENTRANCE**

Publisher address: **UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY**
Kliment Ohridski Bul., 10, Sofia, 1797, BULGARIA
<http://inno.ltu.bg>
<http://www.scjournal-inno.com/>

CONTENTS

DESIGNING AN ICONOSTASIS OF AN ORTHODOX CHURCH.....	5
Asparuh Atanasov, Aleksandrina Bankova	
DATA ENVELOPMENT ANALYSIS OF FACTORS FOR FOREST INDUSTRY WAGES AND SALARIES LEVELS IN NUTS 2 REGIONS OF BULGARIA.....	12
Nikolay Neykov, Radostina Popova-Terziyska, Emil Kitchoukov	
INVESTIGATION OF THE INFLUENCE OF SOME FACTORS ON THE STRENGTH AND STIFFNESS OF JOINTS WITH STAPLES AND GUSSET PLATES.....	18
Desislava Hristodorova, Nelly Staneva	
DEPENDENCE ON SHRINKAGE AND SWELLING IN CHEMICAL COMPOSITION AND ANATOMICAL STRUCTURE – AN OVERVIEW	25
Martina Todorova, Nikolai Bardarov	
REDUCTION OF FORMALDEHYDE EMISSION FROM WOOD-BASED PANELS BY MODIFICATION OF UF ADHESIVES WITH NATURAL BIOPOLYMERS.....	31
Ján Matyašovský, Ján Sedliačik, Peter Jurkovič, Peter Duchovič, Igor Novák	
MODERN ENGINEERING TECHNIQUES FOR THE PRODUCTION OF MODIFIED POLYSACCHARIDES WITH BIOLOGICAL ACTIVITY.....	41
Dragomir Vassilev, Nadezhda Petkova, Milka Atanasova, Panteley Denev	
SUNFLOWER STALKS AND LIGNOSULFONATE – ALTERNATIVE RAW MATERIALS FOR THE PRODUCTION OF ECO-FRIENDLY MEDIUM DENSITY FIBREBOARDS	47
Julia Mihajlova, Viktor Savov	
BEECH WOOD MODIFIED BY RADIO-FREQUENCY DISCHARGE PLASMA.....	58
Peter Jurkovič, Ján Sedliačik, Igor Novák, Ivan Chodák, Angela Kleinová, Ján Matyašovský	
MODIFICATION OF VARIOUS WOOD SPECIES BY BARRIER DISCHARGE PLASMA	62
Ján Sedliačik, Igor Novák, Ivan Chodák, Angela Kleinová, Ján Matyašovský, Peter Jurkovič	
APPLICATION OF ONLINE PLATFORMS IN TRAINING FOR THE DEVELOPMENT OF PROFESSIONAL DIGITAL COMPETENCES.....	66
Adelina Ivanova, Melina Neykova	
SCIENTIFIC JOURNAL „INNOVATIONS IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN“	78