Application of Collagen Colloid from Chrome Shavings for Innovative Polycondensation Adhesives

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Abstract

This research was aimed at determining the possible usefulness (ecologic, efficiency, and economic) of collagen material, after de-chroming, to modify polycondensation adhesives for application in the woodworking industry. The de-chroming technology of leather chromium waste was proposed in our previous work.[1] In this work, condensation adhesives based on urea-formaldehyde and phenol-formaldehyde were modified with protein hydrolysates. It is known that collagen hydrolysate of chrome-tanned leather waste added to dimethylol urea clearly limits formation of relatively unstable oxy-methylene bridges which may be regarded as potential source of formaldehyde emissions. The aim of this study was to verify the change of glue joint properties in following ways:

- influence of collagen hydrolysate on shear strength properties of glued joints under action of water and high humid conditions; increasing the water-resistance of glued materials,
- development of adhesive mixtures suitable for gluing of wood at higher moisture content,
- influence of collagen hydrolysate on lowering the formaldehyde emissions from wood based panels.

The intended sources of protein hydrolysates were solid waste from leather production (e.g. chromium shavings and chippings, hypodermic and adipose ligament, leather chippings, gelatin production and food packing). These various analytical investigations of this study confirmed significant reduction of formaldehyde emission from wood based panels, increased water-resistance of glued materials, and conforming shear strength properties of glued joints. Application of collagen from de-chromed waste allows improvement of ecologic and economic parameters of bonding processes in the woodworking industry (e.g. eliminating of harmful effects on the environment and lowering of costs at keeping required quality).

Resumen

Esta investigación tiene por objeto determinar la posible utilidad (ecológica, eficiente y económíca) del material colagénico, luego del descromado, para modificar adhesivos policondensados para su aplicación en la industria de la madera. La tecnología de descromado de residuos de cuero al cromo se propuso en nuestro anterior trabajo[1]. En este trabajo, adhesivos de condensación basados en urea-formaldehído y fenol-formaldehído fueron modificados con hidrolizados de proteínas. Se sabe que el colágeno hidrolizado de residuos de cueros curtidos al cromo añadido a dimetilol urea claramente limita la formación de puentes relativamente inestables de oximetileno que pueden ser considerados como fuente potencial de emisiones de formaldehído. El objetivo de este estudio fue comprobar el cambio del conjunto de propiedades de la cola de las siguientes maneras:

- Influencia del hidrolizado de colágeno en las propiedades de resistencia al corte de juntas encoladas bajo la acción del agua y condiciones de alta humedad; aumento de la resistencia al agua de los materiales encolados.
- El desarrollo de mezclas de adhesivos adecuados para el encolado de la madera con mayor contenido de humedad,
- Influencia de hidrolizado de colágeno en la reducción de las emisiones de formaldehído de los tableros de madera.

La fuente de hidrolizados de proteínas son los residuos sólidos de la producción de cuero (por ejemplo, virutas y residuos de cromo, tejido hipodérmico y ligamento adiposo, carnichos de cuero, producción de gelatina y envasado de alimentos). Estas investigaciones analíticas diferentes confirmaron una reducción significativa en la emisión de formaldehído en los tableros de madera, el aumento de la resistencia al agua de los materiales pegados, y conformidad en las propiedades de resistencia al corte de las juntas encoladas. La aplicación de colágeno a partir de residuos descromados permite la mejora de los parámetros ecológicos y económicos (por ejemplo, la eliminación de los efectos nocivos sobre el medio ambiente y la reducción de los costos manteniendo la calidad requerida) de los procesos de unión en la industria de la madera.

A **Technical Note** presented at the 107th Annual Meeting of the American Leather Chemists Association, June 9 - 12, 2011, Treasure Island Resort, Red Wing, MN

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Manuscript received June 1, 2011, accepted for publication June 11, 2011

INTRODUCTION

Urea-formaldehyde (UF) and phenol-formaldehyde (PF) belong among the most used polycondensation adhesives in woodworking industry. Their production is about 4,8 million ton (UF) respectively 1 million ton (PF) per year in Europe. From the view of releasing of harmful formaldehyde (fd), this problem is still not closed. Generally it is known, that even today, adhesives based on animal proteins are used in practice in limited amount; there are leather respectively bone glues. Their water-resistance is quite low. From literature, but also from practice, it is known, that this property is possible to be improved with addition of formaldehyde in the form of formalin or para-formaldehyde, eventually with salts Al^{3+}, Cr^{3+} etc. Just the fact, that UF and PF adhesives contain certain amount of free formaldehyde in the liquid state, and proteins contain amine groups, which are able to bond formaldehyde, is the principle of their utilization for their modification.

Collagen is organic matter, which is included among proteins-amines and it is characteristic compound of animal body. The most used sources of collagen from the leather tanning industry are non-tanned (chemically not cross-linked) waste with following utilization in industries:

- food (collagen packs for food, food gelatin, pharmacy, cosmetics),
- adhesives (classical, included special properties – increasing of the joint elasticity, additives for lowering of formaldehyde emission, ensuring the stability of UF adhesives against humidity – in all cases after relevant modification),
- agriculture (biodegradable foils, activator of growth, surface-active matters, filling preparations for different utilization).

Another source of collagen is chromium-tanned leather waste, which is the risk factor for environment due to presence of Cr^{3+}, which is washed from waste e.g. by acid rains at dumping. At waste water treatment, Cr^{3+} is oxidized to Cr^{6+}, which is carcinogenic. Therefore, there is an effort to use waste as secondary raw material. Waste contains collagen fibrils and large amount of amino-groups reactive with formaldehyde. UF adhesives are used in large scale, and utilization of collagen hydrolysates has not only positive influence on environment, but also on an economically interesting input. The principle of protein gluing is the fact that the protein molecules disperse and unfold in solution. The unfolded molecules increase the contact area and adhesion onto other surfaces, and then the unfolded molecule become entangled with each other during the curing process to retain bonding strength. Selected protein modification techniques could increase the tendency to unfold, and consequently increase the bonding strength. Protein unfolding also could move some hydrophobic amino acids, which are buried inside, outward to increase water-resistance. As protein molecules disperse and unfold in solution, the partly unfolded molecules with certain amounts of secondary structure increase the contact area and adhesion force onto other surfaces, such as wood materials, and interact with each other during the curing process to achieve bonding strength.[2]

Cellulose and lignin, basic components of wood, are able to chemically interact with proteins. Wood is hygroscopic material due to hydrophilic character of cellulose, hemicellulose and lignin, main components of cell walls. All these polymers contain hydroxyl groups eventually groups with oxygen, which bound the moisture through hydrogen bridges. It was proved, that proteins are able to bound on different forms of cellulose, crystalline, amorphous as well as water soluble derivates, what is really used at purification and separation of different types of proteins on celullose.[3] Condensation kinetics of dimethylol urea and its mixtures with urea with hydrolysate of chrome-tanned leather waste (mass fraction in mixture 0.05) in the presence of a variable quantity of phthalic acid, as acid curing agent (within mass fraction limits 0.01–0.1), was studied through TG technique. During condensation of sole dimethylol urea or of its mixture with urea, oxy-methylene as well as methylene cross-links are produced at a ratio of approx. 1:1, presence of leather waste hydrolysate reduces this ratio to approx. 1:2 in favor of more stable methylene bridges. Higher concentrations of phthalic acid (above mass fraction 0.05) lead to formation of a new TG mass decrement wave in the 150–180°C temperature interval, which probably relates to transition of more unstable oxy-methylene bridges to more stable methylene bridges, with splitting-off of formaldehyde. Oxy-methylene bridges may be regarded as a potential source of formaldehyde emissions by cured urea-formaldehyde adhesive films. Hydrolysate of chrome-tanned leather waste and a suitable concentration of acid curing agent distinctly reduced formaldehyde emission from cured urea-formaldehyde adhesive films.[4,5] The modified UF resin adhesive with poly-amidoamine displayed better adhesion strength and enhanced reactivity as revealed by the gel time which indicates the involvement of the dendrimers with their enormous $-NH_2$ functionality at the peripheries in boosting the network structure against stress where they can participate in the aminal formation with their internal secondary amine groups under basic conditions and later as well, with their newly formed hydroxyl groups in the cross-linking reaction under acid condition through splitting of water. A more confirmative FT-IR spectra of cured resins using 3 wt% ammonium chloride in absence as well as in presence of amine modifiers proved appearance of a new peak at 1350 cm^{-1} ascribed to $-CH_3$ groups, broadened carbonyl peaks at 1670 cm^{-1} indicated the existence of carbonyls with different chemical environments that proves the chemical

linking of the modifiers during network formation and curing. DSC thermogram for modified adhesive was significantly different from comparative one, it was more complicated and proved significantly higher reactivity of modified resin.[6]

Various fillers and extenders of polycondensation adhesives are used in wood working industry with the aim to reduce the costs.[7] The part of this paper presents the possibility of replacing technical flour with leather dust formed at leather buffing in relatively large quantities. The application of this material was studied in laboratory conditions at Technical University in Zvolen and the research resulted in industrial scale trials. The method of polycondensation adhesive viscosity regulation with fine fraction of collagen fibers is already patented.

EXPERIMENTAL

Polycondensation resins

Urea-formaldehyde resin used was the commercial type Kronores CB 1100 produced by Kronochem Co. Commercial hardener was added into all UF adhesive mixtures according to recommendations of resin manufacturer in amount of 4% wt. Phenol-formaldehyde resin is the commercial type Fenokol A, produced by Chemko, a.s. Strazske, Slovakia. Both resins are industrially used for plywood bonding.

Preparation of collagen hydrolysate

Technology of VIPO Partizanske for collagen recovery from chromium waste after de-chroming without oxidation to carcinogenic Cr^{6+} was proposed and experimentally verified under laboratory conditions. De-chroming of chromium waste by this technology has following advantages: high approx. 99% efficiency of de-chroming of chromium waste, low losses of collagen by hydrolysis and high cleanness of extracted $Cr_2(SO_4)_3$. Collagen substrate has fibrillar structure, which improves its applications; i.e. de-chroming baths are possible to separate and to process commonly with waste water from tanning. Qualitative parameters of collagen substrate were evaluated after de-chroming at three different temperatures by determination of iso-electric point, amount of residual Cr in collagen substrate, pH value of de-chromed collagen, dry matter content of collagen, content of ash in collagen, and total nitrogen.[1] For further modification of de-chromed collagen hydrolysate, there were used lyotropic agents, inorganic salts, sulphur compounds and compounds of Cu, Fe, Mn in the redox grade II as additives to obtain the supposed parameters. For improvement of polycondensation kinetics in further experiments, collagen hydrolysates were modified by different organic and inorganic acids. All other chemicals used for the experimental work were laboratory grade.

Plywood preparation

Plywood is wood-based board material usually used for testing of polycondensation glue compositions according to European standards. The technological process of plywood production for determination of strength properties and content of free formaldehyde with utilization of collagen hydrolysate was following:

- beech (*Fagus Silvatica*) veneers with the thickness of 1.7 mm,
- moisture content of veneers 4%,
- spread of adhesive mixture with gluing roller in amount of 160 g/m^2.

Plywood was prepared with three layers. Plywood pressing was carried out in electrically heated press FONTIJNE at the temperature of 105°C and specific pressure of 1.8 MPa during the pressing time 5 minutes. After pressing and conditioning, samples for testing of mechanical and physical properties were prepared. The content of formaldehyde was determined by perforator method according to EN 120.

RESULTS AND DISCUSSION

Chemical properties of UF + collagen adhesive mixtures

Time of processing determines the lifetime of adhesive mixture suitable for application. De-chromed collagen hydrolysate was laboratory modified to the values of pH 6.5, 3.8 and 1.2 by different types of acids and to the dry content matter of 45%. We have stated the time of processing of adhesive mixture with addition of hydrolysate (in wt. amount of 5%) into UF resin at temperature of 20°C as follows in the Table 1.

TABLE I
Time of processing of adhesive mixtures with collagen

No.	resin	hydrolysate	pH	time of processing [hours]
1.	UF	—	7.3	**more than 24**
2.	UF	collagen	6.5	**more than 24**
3.	UF	collagen	3.8	**3**
4.	UF	collagen	1.2	**0,25**

The time of processing was shortened by decreasing of the pH value. Hydrolysates modified to the values pH 3.8 and 1.2 caused the strong shortening of the lifetime of UF mixtures to less than 15 min. Optimal pH value of hydrolysate is stated between 4 - 6. pH value was measured on equipment HANNA HI 221.

Dynamic viscosity determines the behavior of proposed adhesive mixtures in the dependence on time. Viscosity of prepared mixtures of UF resin with de-chromed collagen hydrolysate was measured on RHEOTEST RV-2 five-times in time interval depending on assumed processing up to one working shift. Measured values of viscosity are in the Table 2.

Slow increasing of viscosity of adhesive mixture with collagen hydrolysate is caused by $-NH_2$ groups. They are active and react with free formaldehyde present in the resin.

The curing time is another important property of adhesive mixture, determines the speed of polycondensation reaction. De-chromed collagen hydrolysate with the value of pH 5 was applied into UF adhesives and the curing time of adhesive mixtures was experimentally determined. We tested the time of curing of adhesive mixtures of UF resin with 3, 5 and 8% wt. addition of collagen hydrolysate. Results of curing time and pH value of prepared mixtures are in the Table 3.

The series of following comparison trials with three types of prepared collagen hydrolysates were realized according to:

- de-chromed collagen hydrolysate prepared by technology of VIPO Partizanske (Slovakia)[1] – without oxidation of Cr^{3+} to Cr^{6+},

TABLE II
Dynamic viscosity of adhesive mixtures

Adhesive mixture	Time after preparation of adhesive mixture (min)				
	20	170	320	440	590
	Dynamic viscosity [mPa.s]				
UF – standard sample	499	499	511	498	511
collagen hydrolysate	835	840	844	840	838
UF + 3% wt. of collagen	559	607	642	607	773
UF + 5% wt. of collagen	642	535	559	642	702
UF + 8% wt. of collagen	654	511	511	773	793

TABLE III
Curing time and pH value of adhesive mixtures

Adhesive mixture	**Curing time [s]**	**pH**
UF – standard sample	**78**	**7.3**
collagen hydrolysate	**–**	**5.0**
UF + 3% wt. of collagen	**74**	**6.2**
UF + 5% wt. of collagen	**77**	**5.8**
UF + 8% wt. of collagen	**76**	**5.5**

TABLE IV
Results of the formaldehyde content in hardened adhesive mixture

No.	Sample	pH of collagen hydrolysate	content of fd [mg/liter]
1	UF – standard sample	–	**0.131**
2	UF adhesive + hydrolysate VIPO	6	**0.054**
3	UF adhesive + hydrolysate VIPO	4	**0.047**
4	UF adhesive + hydrolysate CSIC	6	**0.057**
5	UF adhesive + hydrolysate CSIC	4	**0.047**
6	UF adhesive + hydrolysate Gelima	4	**0.051**

- de-chromed collagen hydrolysate prepared by technology of CSIC Barcelona (Spain)[8,9,10], (preparation of collagen hydrolysate from Cr-shavings by oxidation of Cr^{3+} to Cr^{6+} and following extraction of chromium from collagen mass and its reduction),

- reference sample of non-tanned collagen Gelima – producer of food gelatine (Slovakia).

All types of hydrolysates were prepared such a way to have comparable parameters to collagen applied into UF adhesives in previous trials. Modified hydrolysates were prepared from collagen powders in laboratory conditions. Neutral or slightly acid pH 5 – 6.5 were adjusted by inorganic acid to the value pH 4. Consequently, the adhesive mixtures were condensed at temperature of 100°C during 30 and 45 min. After polycondensation and conditioning, samples of hardened resin were milled and released formaldehyde absorbed in water was determined colorimetrically. Results shown in the Table 4 confirmed the decrease of formaldehyde content at absorption determination (decrease approx. 30%).

Shear strength of plywood samples

Quality of bonding of proposed adhesive mixtures was verified on plywood samples as shear strength after conditioning in cold water. Adhesive mixtures of UF adhesives were prepared with the aim to verify the influence of modified collagen hydrolysate on physical and mechanical parameters of bonded joints and formaldehyde emission from plywood. These different types of collagen hydrolysates were added into UF resin:

1 a – collagen hydrolysate, 40% dry content matter, hydrolysate of VIPO modified by organic acid,

1 b – collagen hydrolysate, 40% dry content matter, hydrolysate of VIPO modified by lyotropic agent and organic acid,

2 a – collagen hydrolysate CSIC, 40% dry content matter, enzymatic hydrolysis, modified by organic acid,

2 b – collagen hydrolysate CSIC, 40% dry content matter, enzymatic hydrolysis, modified by organic acid and lyotropic agent,

3 a – collagen hydrolysate, 53.1% dry content matter, acid hydrolysis Gelima, modified by organic acid,

3 b – collagen hydrolysate 53.1% dry content matter, acid hydrolysis Gelima, modified by organic acid and lyotropic agent,

7 – reference – UF adhesive without addition of collagen hydrolysate.

Adhesive mixtures consisted of UF resin with the addition of modified collagen hydrolysates in amount of 5% related to the weight of UF adhesive. The shear strength of beech three-layer plywood was determined after the water-resistance test, which is used for UF adhesives with the following cycle: 24 h soaking in water at 20°C. This test was carried out according to the standard EN 314-1. Results of the test are statistical values: arithmetic mean, standard deviation and variable coefficient; there are shown in the Table 5.

Results of shear strength of glued joints after the water-resistance test show, that all samples meet the value required by the standard, but there is the particular decrease of shear strength in comparison with the reference sample.

Formaldehyde determination by perforator and chamber method

The content of free formaldehyde in plywood was determined by perforator method according to standard EN 120, results of the test are shown in the Table 6. Required value of free formaldehyde is 8 mg/100 g abs. dry board.

TABLE V
Shear strength properties after the water-resistance test

No.	standard value [MPa]	$\bar{x}$ [MPa]	s [MPa]	v [%]
1a	1.0	**2.45**	0.336	13.7
1b	1.0	**2.07**	0.468	22.6
2a	1.0	**2.53**	0.218	8.6
2b	1.0	**2.13**	0.372	17.5
3a	1.0	**2.22**	0.249	11.2
3b	1.0	**2.07**	0.393	19.0
7	1.0	**2.86**	0.434	15.2

TABLE VI
Content of free formaldehyde in plywood

Sample	Extinction	Content of formaldehyde mg/100g abs. dry board
1a	0.0457	**2.0**
1b	0.0615	**2.2**
2a	0.1021	**3.7**
2b	0.0949	**3.4**
3a	0.0839	**3.0**
3b	0.1212	**4.3**
7	0.1468	**5.2**

TABLE VII
Emission of formaldehyde from plywood

Adhesive mixture	Emission of fd [mg/m^3]	Standard value [mg/m^3]	Relative decrease [%]
UF – reference	**0,0773**	< 0,124	0
UF + 3%	**0,0627**		19
UF + 5%	**0,0652**		16
UF + 8%	**0,0474**		29

Based on previous experiments, the emission of formaldehyde from plywood was tested by chamber method according to the standard EN 717-1. The addition of de-chromed collagen hydrolysate was in wt. amount 3%, 5% and 8%. Results are presented in the Table 7.

The addition of collagen hydrolysate inside the interval (3 – 8%) lowers emission of formaldehyde in comparison with the reference sample. All boards fulfill the standard requirement (E < 0,124 mg/m^3) and all boards belong to the emission class E1. The decrease of formaldehyde content and formaldehyde emission confirmed an assumption, that between resin and chains of natural collagen polymer is direct chemical bond, and hygienic properties of hardened resin are improved. Acid hardeners and modifiers, due to large amount of $-NH_2$ function groups, changed cross linking and the structure of hardened resin. Bonds had higher strength and chemical stability, the speed of their formation is increased.

ATR-FTIR spectral analysis

Infra-red absorption spectra are the reflection of movements inside the molecules, which inform about forces resisting to deformation of chemical bonds. Each molecule is characterized by the specific peaks, which can be used for quantitative as well as qualitative analysis of organic matters with very similar structure. Absorption spectra were measured by FTIR spectrometer NICOLET iS10 (Thermo Scientific). Spectra of UF resin and the modified adhesive mixture with de-chromed collagen hydrolysate were measured on tablets of hardened samples. Comparison of obtained spectra shows high similarity, Fig. 1.

At 1544 cm^{-1}, there is the peak, which was not present in the comparable spectra of collagen. Its presence can be explained by possible formation of C–OH links at reaction of free $-NH_2$ groups with aldehydes. This is proved by decrease of the peak at 1630 cm^{-1} against the peak at 1544 cm^{-1}; it indicates the decrease of free $-NH_2$ groups. In comparison of our results with results of other authors, we can state the mutual conformity. FT-IR spectra of UF resins modified with poly-amidoamine described by[6,11,12], include peaks indicating the fact, that during the cross-linking and hardening process, chemical bound is created between poly-amidoamine and resin. This is confirmed by the peak of valence vibrations (C=O) at 1670 cm^{-1}, and decrease of intensity and movement of peak from 1100 cm^{-1} (C–O–C) to 1000 cm^{-1}.

FT-IR spectroscopy method also confirmed several assumed chemical reactions between UF resin and collagen hydrolysate. On the base of spectra evaluation, we can state that free $-NH_2$ groups of proteins reacts with free formaldehyde and there is strong covalent chemical bound. At the same time, amount of unstable oxy-methylene bridges decreased in the structure of hardened mixture of UF resin with collagen hydrolysate.

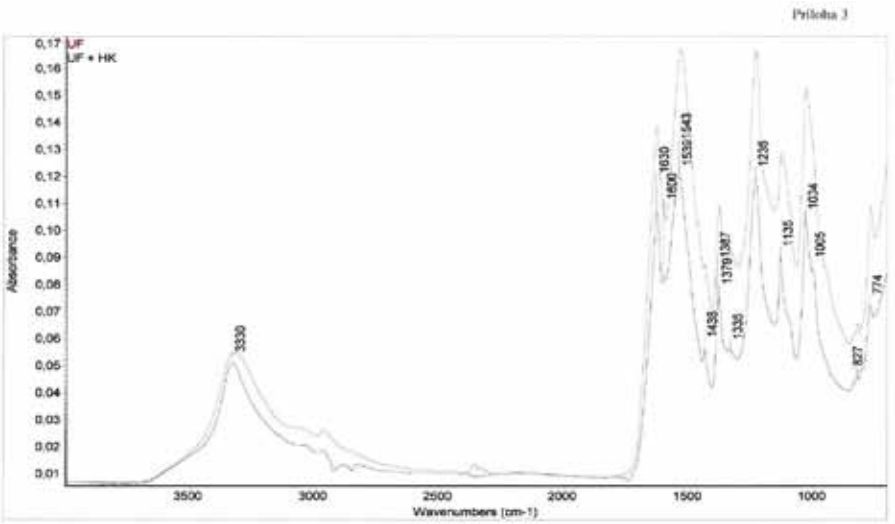

Fig. 1. FT-IR spectra of UF resin and UF resin with collagen hydrolysate

Application of leather dust as extender

UF adhesives are usually extended with technical flour in amount of 20 – 30% for viscosity treatment and ensuring of correct spread of adhesive mixture on glued veneer in general technologic processing. The adhesive composition of UF resin was prepared in different proportions with leather dust, technical flour and curing agent. Leather dust is formed after leather buffing as a fine fraction of collagen fibers. After pressing, the plywood samples were conditioned for one week at the temperature of 20ºC and relative humidity of 65%. Afterwards, test samples were cut and subjected to the water-resistance test with the following cycle: 24 h soaking in water at 20°C (marked as IF-20). The results of the shear strength testing are given in the Table 8.

Plywood samples glued with phenol-formaldehyde adhesive containing leather dust were prepared in a similar way. The test samples prepared from the plywood were subjected to the water-resistance test EW-100 with the following cycle: 4 h boiling at 100°C, 16 h drying at 60°C, 4 h boiling at 100°C and cooling in water at 20°C, according to the standard EN 314-1. The results of the shear strength measurements are given in the Table 9.

It was found out that it is possible to replace technical flour with leather dust in amount up to 7% without significant changes of shear strength for urea-formaldehyde adhesive compounds. For phenol-formaldehyde resins, there is possible to add up to 3% of leather dust while the mixture still have satisfactory viscosity and strength characteristics do not deteriorate.

TABLE VIII

Shear strength of UF adhesive compounds with leather dust

Adhesive composition	UF resin weight parts	Curing agent weight parts	Leather dust weight parts	Technical flour weight parts	Shear strength [MPa]	
					IF-20	Dry
1 – ref.	100	4	0	30	**2.76**	4.35
2	100	4	3	0	**2.10**	3.45
3	100	4	5	0	**2.32**	3.35
4	100	4	7	0	**2.19**	2.97
5	100	4	3	5	**2.40**	3.59
6	100	4	5	5	**2.59**	3.60
7	100	4	7	5	**2.82**	3.60
8	100	4	2	10	**2.29**	4.21
9	100	4	4	10	**2.89**	4.31
10	100	4	6	10	**2.94**	4.18

The limit shear strength of plywood according to European technical standards is 1.0 MPa.

TABLE IX
Shear strength of PF adhesive compounds with leather dust

Adhesive compound	PF resin weight parts	Leather dust weight parts	Viscosity [mPa.s]	Shear strength [MPa]	
				EW-100	Dry
1	100	0	285	2.85	2.80
2	100	3	2 660	2.82	2.75
3	100	5	6 193	2.52	2.63

The limit shear strength of plywood according to European technical standards is 1.0 MPa.

CONCLUSIONS

For application of collagen hydrolysates into urea-formaldehyde adhesive mixtures were stated as follows:

- collagen hydrolysate prepared by de-chroming technology hydrolysis has suitable parameters for application into UF adhesives,
- addition of collagen hydrolysate into UF adhesives was optimised to the content of 5%,
- addition of organic acids into collagen hydrolysate is necessary for required kinetics of hardening of UF adhesives (pH = 4 – 6),
- FT-IR spectra confirmed the reactivity of UF resin with collagen and creation of stronger methylene and peptide links,
- confirmed lowered emissions of formaldehyde down to approx. 40%,
- lowered material cost and prolonged stability of viscosity and storage time of adhesives at ensured required physical and mechanical properties of glued products.
- For application of leather dust into polycondensation adhesives were stated as follows:
- technical flour is possible to be fully replaced by leather dust without significant changes of shear strength in urea-formaldehyde adhesive compositions,
- leather dust is possible to be added into phenol-formaldehyde resins up to amount of 3%, while the adhesive mixture still have satisfactory viscosity and bonded joints have conforming strength characteristics.

These carried out experiments confirmed the proposal of real optimized technology for utilization of de-chromed collagen hydrolysate for modification of polycondensation adhesives, mostly urea-formaldehyde, used for production of wood-based materials with improved hygienic properties – with minimized content and emission of volatile formaldehyde.

ACKNOWLEDGMENTS

The authors wish to thank the Slovak VEGA agency projects No. 1/0517/09 and 1/0565/10, project MŠSR-3933/2010-11 co-funded by the Ministry of Education of the Slovak Republic within the granted stimuli for research and development from the State Budget of the Slovak Republic, APVV Agency projects No. APVV-0521-07 and APVV-VMSP-P-0062-09.

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