Application of whey proteins in wood-based panels

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Abstract
It is foreseen that by 2025 the global population will increase by 20% to reach the 8 billion, while together a relative increase in the GDP/C, food consumption and waste volumes is expected. Among the various kinds of wastes, whey, a waste product of the cheese making process arises serious environmental concerns as traditionally it is discharged into water ways or sprayed onto farmland. Scientists are striving to find new applications of whey and in 2008, 6,553 new products containing whey were launched in the market. However the use of whey ingredients in the sector of wood industry is still in early stages. CHIMAR HELLAS S.A., a research company serving the resin and wood-based panels industry and the Greek dairy industry "N. P. Karakanas" in cooperation with the Agricultural University of Athens are carrying out a project for the use of whey proteins in adhesion systems of urea-formaldehyde resins as to improve the properties of particleboards. The project has title "Valorization of cheese dairy and winery wastes for the production of high added-value products" and is co-funded by the Greek National Competitiveness and Entrepreneurship Programme, the European Regional Development Fund and a consortium of three small-sized enterprises. Within the framework of this project, ultrafiltration has been utilised in the concentration of whey and in the fractionation of whey proteins from lactose. Whey proteins were used as additive in glue mixtures of urea – formaldehyde resins at the levels of 1.5, 2.5 and 3.5% while 1.5% of whey proteins were also added during the synthesis process of the resins. The bonding ability of the resins was examined through the production of particleboards 50x50cm. The panels were manufactured, tested and evaluated according to the relative European standards in force. It was found that the addition of whey proteins improves mostly the mechanical properties of the resins and at a lesser extent their thickness swelling, while the perforator values remain practically the same.

Keywords: whey, protein, particleboards, urea-formaldehyde resin, dairy products

1. INTRODUCTION

Whey is the watery portion obtained from cheese manufacturing. Its principal components are lactose (52.0%–58.0%), proteins (18.0%–24.0%) and mineral salts (11.0%–22.0%) (1). Whey proteins are commonly used in the food industry as they perform a number of technical functions. Nevertheless, few reports on the use of whey proteins in other applications are also available on the literature. Guorong Wang et. al. (2) formulated a novel liquid glue for paper based on polymerized whey proteins (PWP) and polyvinylpyrrolidone (PVP) and evaluated it in comparison with a commercial product (control). The experimental glue had comparable bonding strength with the control, showed full substrate failure in the lap-shear strength tests, and exhibited faster setting property than the control. Suraj Sharmaa and Igor Luzinov (3) fabricated and characterized whey protein bioplastics obtained via blending the protein with two natural latexes and egg white albumin. Their study demonstrated that addition of about 10% of the latex and albumin to the whey based bioplastics improves the toughness characteristics of whey based materials without

compromising their strength and stiffness. Zhenhua Gao et al. (4) developed a whey protein based aqueous polymer-isocyanate (API) wood adhesive that was evaluated according to the JIS K6806-2003 standard. It was found that it has compression shear strength performance above the required values for structural use according to the relative commercial standards. Wenbo Wang et al. (5), prepared plywood panels with an adhesive mixture of phenol-formaldehyde resin and whey protein. It was found that the dry strength of the adhesive with the denatured protein was higher than the requirement of the standard JIS K6806-2003, but the wet bond strength was weak for structural wood products.
Whenever whey protein is used as bonding raw material it is firstly subjected to a thermal pre-treatment for about an hour with aim the unfolding of its nature structure and improvement of its reactivity. This treatment is called "denaturation" process and necessitates spending of time and efforts while it incurs additional cost to the final product.
In the current study, CHIMAR HELLAS S.A. has used whey protein without any treatment as additive in a typical urea-formaldehyde (UF) resin with target the improvement of its performance as adhesive in the production of particleboards. This work has been carried out in the framework of the Greek National Project no 19SMEs2009 partly funded by the Greek National Competitiveness and Entrepreneurship Programme (National Strategic Reference Framework 2007-2013) and the European Regional Development Fund.

2. MATERIALS AND METHODS

2.1 Protein concentrate production

Whey was kindly provided by the dairy industry "N.P. Karakanas". Ultrafiltration (UlF) has been utilised in the fractionation of whey proteins from lactose in order to produce whey concentrate (≥85% protein). UlF was carried out in stirred ultrafiltration cells (Amicon), using membranes with 30 kDA molecular weight cut-off. Nitrogen was used as carrier gas (at a maximum pressure of 55 psi). Retentate (whey concentrate) and permeate (lactose) samples were collected and freeze-dried or freezed, respectively, before any further treatment.

2.2 Synthesis of polymers and their characterisation

Technical grade urea and formaldehyde water-based solution of 37% were used for the synthesis of a typical Urea-Formaldehyde (UF) resin suitable for the production of particleboards with molar ratio(MR) F/U 1.07/1. For the synthesis of the resin a technological pathway proprietary of CHIMAR was followed.
The whey protein was used as additive in the resin both during its preparation and in its glue mixture (consisting of resin, water and a typical hardener for UF resins) that was prepared on site of the production of particleboards. The addition levels of the protein in the glue mixture were 1.5, 2.5 and 3.5 % w/w while 1.5% w/w of it was added during the preparation of the resin at two different stages of the synthesis process.
The typical UF resin as well as the experimental ones were subjected to lab analysis for the determination of their physicochemical properties. In each case the solid content of the resin was determined by weighing a mass of about 2g (±0.0001g) before and after drying in an oven of 120°C for 2h. The viscosity of the resin was determined with a Brookfield rotational viscometer using a LV series spindle at 6 rpm rotational rate. pH was measured at 25°C using a Crison pH meter. The water tolerance of the resin was determined by adding drop wise water in 10ml of the resin until precipitation was observed. The gel time is the time needed for 5ml of resin to cure when 3.5% w/w of a hardener is added, while the glue mixture is continuously stirred in a water bath of 100°C. The buffer capacity of the resin was determined with 0.1N H_2SO_4 and its free formaldehyde content was determined according to the standard EN 11402:2004.

2.3 Production of particleboards

The resins were evaluated for their adhesion properties through their application in the production of single layer particleboards following the industrial practice. The resin mixtures were blended with wood particles (chips) and formed into panels (mat). The underlying principles of this stage is the production of an evenly distributed layer of particles.

The mat was transported initially to pre-press and then to hot press where the final curing of the resin took place and the final product was formed. In this case, particleboards of dimensions 44x44x1.8cm and density of 580kg/m^3 were produced.

The panels were tested according to the European standards, for the following properties:

-Resistance to tensile strength (Internal bond) in accordance with the standard EN 319:1993

-Flexural strength (Modulus of Rupture) in accordance with the standard EN 310:1994

-Thickness swelling in water in accordance with the standard EN 317:1993.

-The humidity of the boards was determined according to the method of the standard EN 322:1993.

-The formaldehyde content of the panels was determined with the Perforator method as described in the standard EN 120:1992.

The properties of the particleboards manufactured with glue mixtures that contained whey protein were compared with the ones produced with a straight UF resin.

3. RESULTS AND DISCUSION

The properties of the typical UF resin and the ones where 1.5% whey protein was added at different stages of the synthesis process (namely stage A and B) are cited in the following Table 1.

Table 1: Properties of resins

Resin:		UF107K	UF107K	UF107K
% protein		-	1.5	1.5
Addition stage			A	B
Solids	%	66.41	68.00	66.55
Viscosity, @ 25°C	cP	265	710	335
pH	[ ]	8.24	8.06	8.03
Free Formaldehyde	%	0.180	0.152	0.174
Buffer Capacity (0.1N H_2SO_4)	ml	13.3	11.4	14.0
Water tolerance, at 25°C	ml/ml	1 / 2.7	1 / 10.0	1 / 5.7
Gel time at 100°C	s	61	56	57
Specific gravity at 20°C	[ ]	1.287	1.299	1.287

The results show that the experimental resins have higher viscosity and significantly improved water tolerance while the addition of whey protein renders a reduction to their free formaldehyde content. The experimental resins have also reduced gel time which means that they set faster than the typical UF resin.

The properties of the particleboards measured according to the relative European standards are presented in the following table 2.

Table 2: Properties of particleboards

Formula No		**1**	**2**	**3**	**4**	**5**	**6**
Resin type		UF107K	UF107K	UF107K	UF107K	UF107K	UF107K
Protein level, % s/s		-	1.5	2.5	3.5	1.5	1.5
Addition of protein in		-	Glue mix	Glue mix	Glue mix	Resin	Resin
Addition stage		-	-	-	-	A	B
		Long pressing time					
Internal Bond, Ave	N/mm^2	0.28	0.40	0.35	0.23	0.34	0.31
SD		0.09	0.12	0.07	0.04	0.06	0.08

Thickness Swelling 24h, 20^{o}C, Ave	%	46.2	37.0	40.8	39.3	40.8	41.5
SD		2.62	3.83	2.43	2.04	2.15	1.93
Modulus of rupture	N/mm^2	11.15	9.51	10.63	10.04	12.07	10.83
		Short pressing time					
Internal Bond, Ave	N/mm^2	0.28	0.42	0.33	0.29	0.27	0.30
SD		0.03	0.06	0.08	0.06	0.09	0.03
Thickness Swelling 24h, 20^{o}C, Ave	%	44.6	35.8	42.3	40.6	40.3	39.4
SD		3.18	1.35	3.23	1.18	3.35	1.59
Modulus of rupture	N/mm^2	10.28	10.20	11.39	10.40	12.15	9.48
Formaldehyde content at 6.5% MC	mg/100 g	5.32	5.62	5.61	5.40	5.31	5.14

The results show that the addition of whey protein in a UF107K resin for particleboard production improves mostly the mechanical properties of a panel and at a lesser extent its thickness swelling, Its bending ability and the perforator values remain practically the same. Furthermore, it is clarified that whey protein gives rather better results when added to the glue mixture than during the synthesis of the resin. Addition of whey protein in the glue mix at levels higher than 1.5% does not render a higher performance to the resin.

4. CONCLUSIONS

The adhesion performance of Urea-Formaldehyde resins can be enhanced with the addition of untreated whey protein at levels lower than 3.5% either during the synthesis of the resin or in its glue mixture during the production of particleboards. In particular it was found that even only 1.5%w/w addition in the glue mixture was enough for giving panels with about 46% higher tensile strength and 20% lower thickness swelling while all the other properties were remained practically unaffected. Whey protein is a by-product of the dairy industry and its use in UF resins provides a solution for its further use in added-value applications.

5. Acknowledgment

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6. References

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