ENVIRONMENTAL BIOTECHNOLOGY 5 (2) 2009, 57-60

Elimination of formaldehyde emission from wood-based boards*

Iwona Frąckowiak[1], Jacek Rudnicki[2], Aleksandra Sokołowska[2]

[1] Wood Technology Institute, 60-654 Poznań, Poland, Email: i_frackowiak@itd.poznan.pl
[2] Faculty of Materials Science and Engineering, Warsaw University of Technology, 02-507 Warszawa, Poland

ABSTRACT

Glue, a formaldehyde (HCOH) based resin, is an indispensable constituent of wood-based boards. However, formaldehyde evaporates during the manufacturing process, during exposure (furniture), and also during waste disposal. Since it belongs to the group of carcinogenic compounds, restrictions on its emission from wood-based boards have been imposed all over the world. Among the methods developed for diminishing this toxic emission, there have been the synthesis of the glue which permits reducing the mol percent of HCOH, or binding HCOH *in situ* by ammonium salts. In this study we propose a solution of the problem, namely a new glue, based on poly-silicon polymers, which has an optimized viscosity and wets the wood well. The new ligno-cellulose/poly-silicon composite has the required mechanical properties and is absolutely harmless to the environment.

INTRODUCTION

Wood is a unique constructional material: it is renewable, harmless for the environment, and its specific strength (E/ς) is comparable with that of metals. Wood is utilized totally, since its scraps in the form of shavings, fibers, sawdust and the like are the basic components of wood-based composites such as chipboards, fiberboards, plywood etc. The production of wood-based materials manufactured in Poland constitutes a substantial part of Polish economy. These materials are used for manufacturing indoor fitments (furniture, walls, floors etc.) for buildings intended for people to live or work.

The glue that joins together wood scraps is an indispensable constituent of wood-based materials. It must wet the wood well, adhere to it, must be hydrophobic, and resistant to bacteria. Its mechanical properties must be comparable to those of wood, and its vitrification temperature must be lower than that at which wood undergoes chemical changes. Moreover, it is desirable that the glue should be easily mixed with water and should be inexpensive. These requirements are fully satisfied by poly-condensation formaldehyde-based resins – phenol-resins and amino-resins of various kinds. About 60% of these resins are produced for purposes of the industry of wood-based materials.

Formaldehyde is however an irritant and toxic gas. Studies on its effect on animals have shown that it is also cancerogenic (Kerns et al. 1983; Swenberg et al. 1980). Therefore formaldehyde is a substance harmful to people and environment. It is emitted into the atmosphere during the production of glues for wood-based materials, during the manufacturing of these materials, during the exploitation in closed rooms of products made of them (furniture in flats and offices), and also when these products are incinerated. Because of all these undesirable effects, formaldehyde should be eliminated or at least its emission should be minimized.

Table 1. Mechanical properties of Silkit.

Ultimate tensile strength	Elongation to failure	Hardness	Density 25°
1.5MPa	400%	22°ShA	$0.96 g\cdot cm^{-3}$

Examinations performed according to EN 310

* Presented at the Second International Environmental Best Practices Conference, 14-18 September 2009, Krakow, Poland.

Table 2. Mechanical properties of "ecoplywood".

Tested piece	Bonding quality	Bending strength ($N \cdot mm^{-2}$)	Modulus ($N \cdot mm^{-2}$)
"silkit glued" thick	0.32	12.3	400
"silkit glued" thin	0.28	20.4	756
"AC4A glued" thin	0.92	58.3	1493

S=2.06; s=58.5.

$f_v = \frac{F}{l_1 x B_1}$ Bonding quality according to PN-EN 314-1: 2002, where:
F = failing force on the piece,
l_1 = length of the shear area,
B_1 = width of the shear area.
Examinations performed according to PN-EN 310:1994; six replicates investigated; S = deviation.

Regulations limiting the emission and content of formaldehyde in wood-based boards and its reduction of NDS at workplaces in the factories that produce these boards were first introduced in the 1970s. In those years in Poland, under the threat that the export of furniture would not be possible, the content of formaldehyde was reduced more than tenfold thanks to the cooperation between chemical works, fiberboards manufacturers and scientists. The concentration of this substance at workplaces and its emission into the atmosphere from the production lines were also decreased. Since then, the formaldehyde problem is discussed unendingly, and the discussion has been intensified since June 2004, when the International Agency for Research on Cancer, a branch of the World Health Organization, changed the classification of formaldehyde to place it in the group of cancerogenic compounds. The fulfillment of the current requirements as to the content and emission of formaldehyde and an improvement of methods of their testing may be an absolute condition for further development of the production and export of wood-based boards and furniture. A very restrictive regulation has already been introduced in Japan (JIS A: 59005 standard – chipboards and 5908 – MDF boards for the building industry). On 1 January 2009, in California, USA, the Council for Air Resources enacted a regulation restricting the emission of formaldehyde from wood-based materials to a level much below that obligatory in Europe. In 2005, Finland in agreement with the German Federal Board for Environment Protection, moved a motion to the European Commission postulating that the level of formaldehyde emission should be reduced to 25% of the value obligatory thus far. In 2009, the IKEA Company, one of the most powerful foreign investors in Poland, implemented the Low Emission and Zero Tolerance for Formaldehyde Projects.

Detailed laboratory examinations by the 'Chamber' method, i.e. by measuring the concentration of formaldehyde emitted from various wood-based materials in a closed room (Oue and Furuno 2007) have shown that, in addition to the wood-based boards, also other objects present in this room may be the sources of formaldehyde emission, and that this emission is not additive, i.e. the emission which predominates is always from the objects whose emission is most intensive. The measured concentration of formaldehyde emitted from wood-based boards under normalized conditions ranged from 0.30 to 0.73ppm.

Common standards to test the emission of HCOH rely on gas analysis. Threshold value for HCOH emission according to the legislation is $3.5 mg \cdot m^{-2} \cdot h^{-1}$. In attempts of reducing the emission of formaldehyde, the synthesis of urea-formaldehyde poly-condensate is conducted at a strongly acidic pH, which decreases the formaldehyde/urea mol ratio by almost an order of magnitude. Another way is to introduce substances

Table 3. "Ecoplywood" swelling in water.

Feature	Polastosil AC4A		Silkit	
Length %	1.32	1.04	1.54	3.01
Width %	6.11	5.63	6.08	8.69
Thickness %	8.67	7.83	5.27	7.51
Mass %	38.27	102.18	39.94	101.61
Treatment	24h bath in water	6h boiling in water	24h bath in water	6h boiling in water

Six replicates investigated.

that bind chemically formaldehyde (urea and other ammonia salts) when, during their manufacture, the wood-based boards are subjected to pressing.

Our studies were aimed at the radical elimination of formaldehyde emission by replacing the formaldehyde based resin glues with another glue which satisfies the requirements of the technology of wood-based boards and, at the same time, is entirely friendly to the environment at all stages of the production and exploitation. Results of preliminary investigations were presented during the Conference "Wood – Material of XXI Age" (Sokolowska et al. 2008).

Materials competitive to organic polymers are poly-silicon polymers. Silicon is iso-electronic to carbon and, by utilizing the hybrid σ sp^3 structure, can form long macromolecules.

The silicon polymers are absolutely non-toxic, and at a temperature above 150°C decompose into SiO_2. Therefore, these polymers are entirely ecology-friendly, and thanks to their surface properties behave well in contact with other materials.

There is only scarce information about the use of organo-silicon polymers as the substitutes for the macromolecular carbon-chain materials intended for sticking together fibers and pieces of wood (plywood, chipboards, fiberboards and the like). The organo-silicon compounds are mostly applied in impregnation of wood or in wood surface treatment (Mai and Militz 2004). Impact absorbing floor built partly of polysilicone rubber plates (Tsutomu 1989), composite material consisting of wood particles, zeolite and polysilicone (Fisher et al. 2005), binder in lignocellulose basing composites (Edelman et al. 2010) are described in patents.

MATERIAL AND METHODS

In our experiments we produced three–layer pine plywood glued with polysilicone. We focused on the use of neutral single-component rubbers, known as Silkit, Polastosil AC-4A and

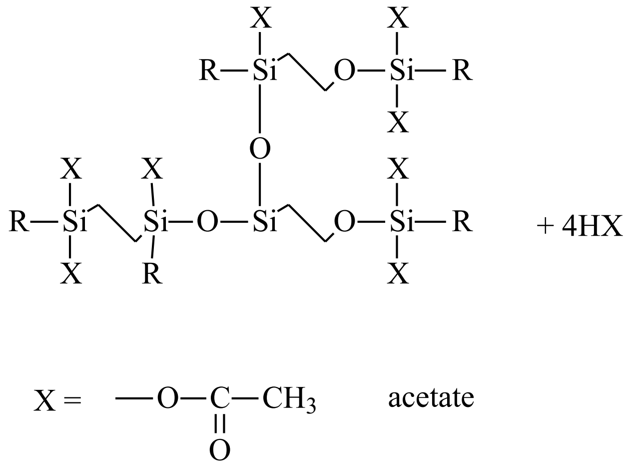

Figure 1. Silkit chemical formula.

Polastosil M2000 (Polisilikony Polskie Sp. z o.o. Nowa Sarzyna, Poland) crosslinking at room temperature with the participation of water. The formula describing Silkit is given in Figure 1. Attempts at applying two-components poly-silicon rubber Polastosil M56 failed since it did not adhere to the wood. The physical properties of the Silkit are summarized in Table 1. The wood wettability with one-ingredient glues was so high that only pressing the veneers together under a pressure of 0,5MPa at a room temperature during 4 hours was sufficient to obtain a plywood. The properties of the produced plywoods were examined using standard methods described in European Standards EN. Combustibility test was performed on Cone Calorimeter (Fire Testing Technology FTT Ltd., East Grinstead, U.K.) at thermal radiation flow at $50 kW·m^{-2}$ in air according to standard ISO 5660-2. The main parameter, the heat release rate (HRR), was determined from oxygen content in combustion gases.

Table 4. "Ecoplywood" combustibility tests.

Material	**Ignition time** (s)	**HRR** ($kW·m^{-2}$)			
		1min	**3min**	**5min**	**Mean**
Commercial plywood	27	163.29	138.27	187.53	167.47
Polysilicone plywood	28	150.33	117.16	198.09	161.81
HRR peak ($kW·m^{-2}$)	**THR** ($MJ·m^{-2}$)	**MLR** ($g·s^{-1}$)	**Smoke** ($m^2·m^{-2}$)	**CO** ($kg·kg^{-1}$)	**CO_2** ($kg·kg^{-1}$)
351.83	65.4	0.325	125.1	0.0153	1.28
283.99	86.9	0.208	263.4	0.0122	1.26

HRR – heat release rate,
THR – total heat release,
MLR – maximum mass loss rate,
Two replicates investigated.

RESULTS

Table 2 lists mechanical properties of the produced plywoods. In Table 3 swelling in water of these plywoods is compared. The plywood glued with Silkit was also additionally tested on combustibility, and the results are presented in Table 4.

The best results were obtained for plywood glued with Polastosil AC-4A, for which the bonding quality was 0.92, what was a satisfying result because the bonding quality for traditional plywood is 1.00 (according to PN-EN 314-1 standard). The disadvantages of the elaborated "eco plywood" are non-satisfactory glue infiltration into the wood for purposes of protection against swelling in water and the relatively large amount of dust emitted during combustion due to the generated SiO_2.

CONCLUSION

The results have proved that the polysilicone rubber as a binder can effectively substitute formaldehyde-based resins glues. The development of the technology of wood-based materials involving the use of polysilicone will permit the formaldehyde emission to be eliminated at all stages of the production, exploitation and disposal.

ACKNOWLEDGEMENTS

Supported by the Polish Ministry of Science and Higher Education grant No. N50701832/0599.

REFERENCES

Edelman, R., B. Standke, P. Jenkner, J. Monkiewicz, A. Kharazipour, L. Kloeser. 2010. German Patent Application.

Fisher, E., R. Wypart, B. Marcus. 2005. U.S.Patent 20070078050.

Kerns, W.D., K.L. Pavkov, D.J. Donnofrio. 1983. Carcinogenicity of formaldehyde in rats and mice after long-term inhalation exposure. Cancer Research 43: 4382-439.

Oue, Z., T. Furuno. 2007. Formaldehyde emission from wood products: Relationship between the values by he Chamber method and those by the Desiccator test. Wood Science and Technology 41: 267-279.

Mai, C., H. Militz. 2004. Modification of wood with silicon compounds. Treatment system based on organic silicon compounds – A review. Wood Sciences and Technology 37: 453-461.

Sokolowska, A., I. Frackowiak, W. Jaskolowski, J. Rudnicki, J. Szymanowski, P. Beer. 2008. Annals of Warsaw University of Life Sciences 256-257.

Swenberg, J.A., W.D. Kerns, R.I. Mitchell, E.J. Gralla, J.L. Parkov. 1980. Induction of squamous cell carcinomas of the rat nasal cavity by inhalation exposure to formaldehyde vapor. Cancer Research 40: 3398-3402.

Tsutomu, T. 1989. Patent Publication Info JP 1235770.