Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 6, Part 2

ODIFIED NANOCOMPOSITE WOOD FIBROUS MATERIALS FOR SPECIAL APLICATIONS

Radka Iv. Garvanska [1], Peter N. Velev [1], Mirela M. Dragnevska [2],
Svetla D. Lekova [1], Svetlin B. Parvanov [1].
1 University of Chemical Technology and Metallurgy, 1756 Sofia, Bulgaria
2 Lesoplast AD, Troian, Bulgaria

Abstract

Wood fibrous composite materials with special properties as improved electroconductivity, microwave absorption capacity, antiseptic ability, high physical- mechanical indices, but and with high quantity of wood component represent a great interest because of their unique properties and possibilities for different applications.

An original method for obtaining of cupper – sulfide modified nanocomposite wood-fibrous materials has been developed. A mathematic modulation and optimization of the process is conducted using phenol-formaldehyde resin as connect agent. Cupper–sulfide modified nanocomposite wood-fibrous materials with improved electroconductivity for electromagnetic wave protection are obtained.

Key words: *cupper – sulphide wood nanocomposite, phenolformaldehyde resin, electro conductivity*

1. INTRODUCTION

In the recent years, the increase use of wood polymer composites in technique and way of living is observed. In this respect the nanoscience and technology give unique possibilities for creation different combinations of new materials. The metal-containing nanocomposites and polymeric nanocomposites in particular, with their unique physical and chemical properties as well as the broad areas of application have been attracting a great interest (Wang 1998).

Composites with improved parameters, including toughness, thermostability, and other specific properties, can be obtained via adding mineral fillers, metals, and fibers to polymers. Recent progress is being marked by the development of nanocomposite materials comprising a low percent of filler that have much larger intrinsic surface area, hence better parameters than the conventional composites (Lio 1995).

Nanocomposites include linear, as well as three-dimentional and amorphous structures of intermixed phase-separated nanocomponents. A considerable advantage of the nanocomposite materials are the uncomplicated and cheap preparative methods and technologies. It has been established that all mentioned types and classes of nanocomposite materials have improved properties in comparison to the similar macrocomposites (Lio 1993). Hence, nanocomposites allow new applications, such as lighter components for reinforcement, nonlinear optical systems, cathode and anode batteries, sensors, etc.

An original method for formation of metal-containing polymers via thermal decomposition of precursors (mainly metal carbonyls) in solution or melt has been published. A strong interaction between the nanoparticles and the polymer chain occurs in such nanocomposites on the level of

chemical bonding. Electronically dense individual or aggregated metal-containing particles have been observed (Pomagalio 2000; Hershaw 1999).

Recently, special attention has been paid to nanocomposites having a different controllable molecular structure, determined by the polymeric dendrimers. The metal organic derivatives of dendrimers and their numerous macromolecular metalcomplexes of ruthenium, palladium, platinum, etc., are well known (Zend 1997; Floriano 2001; Grohn 2001; Wang, 2000).

Nanocomposites allow the production of articles possessing superconductivity. It has been noted that the investigations in this field open possibilities of obtaining new materials with unique properties (Wang 2000; Wu 1989a,b).

The method of direct precipitation of colloidal dispersed additive layers and their encapsulation into the polymer matrix has been recommended as one giving a lot of possibilities to the applications of the obtained materials (Bissessur 1993). A new method for in-situ synthesis of precious nanoparticles using cellulose supports has been developed (Sun 2002).

Methods for modification of fabrics with electroconductive pigment on the basis of copper sulfide polymer dispersion have been developed; these include new electro-conductive polyacrylonitrile (PAN) pigments with coordinative connecting of copper sulphide in the nanostate into the PAN matrix for microwave protection (Lekova 1998)

Recently, investigations connected with copper sulphide coating on polyacrylonitrile with a chelating agent of triethanolamine (Chen 2009) and ethylenediaminetetraacetic acid (Chen 2010) by an electroless deposition method and its EMI shielding effectiveness have received great interest. The literature study showed that the obtaining of new metal-containing nanocomposites polymer materials with improved electroconductivity and microwave absorption ability is a question of present interest and it is very useful for articles that can provide electromagnetic wave protection.

In this study, copper sulphide-containing nanolignocelluloses with improved electro-conductivity and microwave absorption ability have been developed, and on this basis polymer composites with special new properties for electromagnetic wave protection have been obtained.

The purpose of the present research is the development a method for production of copper-sulphide wood-polymer nanocomposite materials and this method to be adoptable to the existing equipment and technology for wood fiber plates (WFP) production in LESOPLAST Inc. – Troyan.

The researches comprise:

- Experiments on development of appropriate and optimal method for wood fiber material modification to obtain copper-sulphide lignocellulose nanocomposites;

- Experiments on defining the technological stage and adequate equipment to obtain copper-sulphide wood fiber nanocomposite plate materials;

- Modelling and optimization of the developed method in respect of compositions, proportion of the individual components and parameters by using phenol formaldehyde resin as bonding agent for the achievement of improved electrical conductivity (corresponding electromagnetic wave absorption), high content of wood component and with retaining the level of the initial standardized WFP characteristics.

2. MATERIALS AND METHOD

In present investigations are used:

- wood fibers – high gain fibrous material (HFM), obtained in Lesoplast AD, Troyan by hydro heat treatment of wood chops for wood plates; and

- phenol formaldehyde resin – content 0,1 % towards the fibers as bonding adent of wood fibrous composites.

Before mathematic modeling and optimization of process for obtaining of cupper–sulfide modified nanocomposite wood-fibrous materials, preliminary experiments for establishing of suitable technological modification stage have been carried out.

Experiments for establishing of technological stage

.* The obtained results on the stage, consists by treatment of technological chops in steaming chamber, showed that the modification process do not pass uniformly in the depth of wood and stayed on the surface or in the solution. This unevenness of modified and unmodified fibers in wood sample carpet will bring to bad results regarding electroconductivity. Therefore, the stage with steaming treatment of technological chops is not suitable as a modification method.

.* On the gluing stage of wood fibrous mass, the modification process is carries out in the volume of wood fibrous mass by homogenization $CuSO_4 5H_2O$: $Na_2S_2O_3$ $5H_2O$ solution in proportion 1:2 with fibrous suspension. Obtained samples do not possess good results regarding electro conductivity. This may be explained by considerable loss of modified reagents. These previous results showed the advisability for conducting the treatment of wood fibers by surface modification with mixture of $CuSO_4$ $5H_2O$:$Na_2S_2O_3$ $5H_2O$ on the stages - gluing and formation of wood fibrous carpet. Such manner of working will give the possibilities for minimal losses of reagents and for one full finished method of modification.

On the basis of experimental results are established conditions and starting parameters, as fowling:

1. The quantity of reagent mixture $CuSO_4 5H_2O$: $Na_2S_2O_3$ $5H_2O$ towards absolute dry wood fibrous mass – 25%, 35%,45% (step 10) - x_1
2. Mole proportion $CuSO_4 5H_2O$:$Na_2S_2O_3$ $5H_2O$ - 1:1, 1:1,5, 1:2 (step 0,5) - x_2
3. Duration of staying before pressing - 7, 12, 17 minutes (step 5)- x_3

Constant parameters

1 Temperature of pressing - 170 ÷ 175° C

2. Duration of staying before pressing – 10 minutes

The experiments are carried out with wood fibrous mass from production of Lesoplast AD- Troyan with fowling indexes: concentration – 3,75%; grinding degree – 22DS; 15 % CFR and 10 % paraffin emulsion. The quantity of gluing substance is 1 % towards absolute dry wood fibrous mass. The experiments are conducted with specimens- sixes 30x30 cm. by surfacing treatment with the mixture of reagents. The obtained samples have 15 % wood fibrous material. The fowling process is pressing- 170 ^{0}C, duration -10 minutes.

The specimens are characterized in respect of electrical conductivity (volume electrical resistance by apparatus DC- MILLI- PICO- METER MV 40, VE KOMBINT PRACITRONIC, Dresden, as well as the bending strength by apparatus ZWICK Z0,5 Zwick & Co GmbH, standart EN 622-1. The swelling is determined according EN 622-2.

3. ANALYSIS AND DISCUSSION

In the present work, the modeling and optimization of the modification process of the wood nanocomposites are conducted with the fowling main performance characteristics (outputs):

- y_1 – bending strength on face, [MPa];

- y_2 – bending strength on sieve, [MPa];

- y_3 – swelling in water, [%];

- y_4 – logarithm of the volume resistivity, [Ω].

These outputs are depended by the influence of the three process parameters (factors): x_1 - % modification additive of two reagents towards absolute dry wood fibrous (WF) mass, x_2 – mole proportion $CuSO_4$ $5H_2O$:$Na_2S_2O_3$ $5H_2O$; x_3 – duration of staying before pressing [min.]. Changed limitations are: $25 \leq x_1 \leq 45$, $1 \leq x_2 \leq 2$ and $7 \leq x17$.The weight of absolute dry WF mass at experiment is constantly, but the additives have different percent and mole proportions. By this reason WF mass and additives do not observed as three mutually dependent variable quantities.

The aim of the optimization problem is to find a great number of suitable combinations of two additives (factors x_1 and x_2), as a duration of staying (x_3) at which the bending strength (target function y_1 and y_2) is over 30 MPa and swelling under 37%.

The decision of the optimization problem

For the decision of so formulating task is selected a model based approach, especially regression model, which describes the relations of the outputs y_j, j=1,2,3,4 and factors x_1, x_2 и x_3 .. Since in examining sphere of changing of factors there are not unsteady changing of initial quantities, the mathematical model must search in the class of polynomial models:

$$\hat{y}_{ju} = \sum_{i=1}^{k} b_i f_{iu} \, . \qquad (1)$$

Where, u = 1, 2,…N is number of attempt, i = 1, 2,... k – numbers of coefficients in the model. **b** =[b_1 b_2 ... b_k]^T – к-verse vector of valuations of regression coefficients. f_{iu} – random, previous given of factors (x_1, x_2 и x_3), $\hat{y}_{ju}$ – predict value of aim function. This function is received by replacement of values of f_{iu} for every experiment.

The organization of the experiment is very significant for the effectiveness of the investigation. In this case the experiment is conducted using optimal composition plan with 14 attempts (N=14 experiments).

In present work models of complete second order with 10 adequate for 4-th target functions coefficients are considered. After a control for significance of regression coefficients by t- Student criteria, the coefficients for all models ahead of the x_3 и x_3^2

are insignificant and are not included in models.

In Table 1 the obtained regression coefficients are given. In Table 2 the obtained results from statistic analysis of the models are summarized. Q_{jr} Means the residual sum of quadratics of corresponding models.

Where, $\hat{y}_{ju}$ - is the predict value on j – model in u-attempt.

This predicted value characterizes the dispersion of experimental values of initial

y_{ju} near to the predicted model values. The reason of the showing may be due of:

а) non adequate of the model ;

б) influence of accident error.

The model may be suitable for using (prediction and optimization) if the influence of non adequate is commensurably or lower in comparison with the influence of accident error. This may be ascertained by the comparison of dispersions. The valuation of dispersion, connected with Q_{jr} is calculated.

$$s_{jr}^2 = Q_{jr} / v_{jr}, \tag{3}$$

Where $v_{jr} = N - k$ is the number of degrees of freedom. It is compared with the valuation of dispersion of random error $s_{j\varepsilon}^2$. For valuation of the adequate of model [1] the repeated experiments n_j, j=1,2,3,4 at the same regime in centre of the plan x1 =35, x_2 =1.5 и x_3 =12 have been conducted. These experiments give the possibility to estimate the dispersion of the random error $s_{j\varepsilon}^2$:

$$s_{j\varepsilon}^2 = \frac{1}{n_j - 1}\sum_{i=1}^{n_j}(y_{ji} - \bar{y}_j)^2, \qquad j = 1 \div 4,$$

Where n_j is the number of observations, $\bar{y}_j$ - arithmetical mean. Number of freedom degrees is

$v_{j\varepsilon} = n_j - 1$.

The comparison is founded on the control of zero hypothesis H_0: $s_r^2 = s_\varepsilon^2$, by F- criteria of Fisher. The Table 2 shows the level of significance.

$$Q_{jr} = \sum_{u=1}^{N}\left(y_{ju} - \hat{y}_{ju}\right)^2, \qquad j = 1 \div 4 \tag{2}$$

Table 1 Regression coefficients

Included function f_{iu}	Coefficients in the model for y1	Coefficients in the model for y2	Coefficients in the model for y3	Coefficients in the model for y4
Своб. член	41.2294	17.6177	29.4281	10.4293
x_1	-3.6620	-4.8395	-4.2500	-0.2240
x_2	5.6285	7.3530	6.4910	-0.1655
$x_1 * x_2$	-0.3069	-4.5506	-2.4300	-0.1631
$x_1 * x_3$	-1.9931	-1.6531	-1.8250	0.0288
$x_2 * x_3$	-1.8431	0.1919	-0.8250	0.0319
x_1^2	0.6487	3.1321	1.8888	0.0897
x_2^2	-2.4438	6.8996	2.2238	0.0021

Table 2 Level of significance

Model	Q_r	v_r	s_ε^2	v_ε	F-calculated	Fкр (α = 0.05)
У1	27.74	6	9.15	3	1.97	4.76
У2	64.50	6	12.99	5	1.21	4.39
У3	15.74	6	2.92	2	1.11	5.14
У4	0.141	6	0.025	17	1.08	3.92

The searching of optimal regimes are realized by the method of scanning with constant step, which represents 5 % of observed field of changing of each factors.

Optimal regimes depending on special requirements for different applications of new cupper – sulfide modified nanocomposite wood fibrous materials are developed.

The optimal regimes for reaching of minimal swelling; maximal strength on the face; maximal strength on the sieve; maximal strength on the face and on the sieve; and minimal electric resistance are given in following blocks N 1 to 5.

Block 1:Optimal regimes for obtaining of minimal swelling

Setting limitations: y1>30; y2>30; y3<31

X1	X2	X3	Y1	Y2	Y3	Y4
27	1.7	16	47.2185	30.1146	30.3374	4.406E+10
27	1.7	17	47.3900	30.3944	30.3453	4.385E+10
31	1.9	7	46.5122	30.9942	30.4829	2.757E+10
29	1.8	12	46.2679	30.1828	30.6581	3.599E+10
29	1.8	13	46.2859	30.4042	30.7391	3.602E+10
29	1.8	14	46.3039	30.6256	30.8201	3.605E+10
29	1.8	15	46.3219	30.847	30.9011	3.608E+10
29	1.8	16	46.3399	31.0684	30.9821	3.611E+10
31	1.9	8	46.3767	31.1572	30.637	2.775E+10
31	1.9	9	46.2413	31.3201	30.7911	2.793E+10
31	1.9	10	46.1058	31.4831	30.9452	2.811E+10
33	2	7	46.6783	33.3511	30.9556	2.094E+10
35	2	7	46.2572	31.6784	30.6814	1.714E+10
35	2	8	45.8886	31.7168	30.9316	1.740E+10
37	2	7	45.888	30.2563	30.5346	1.427E+10
37	2	8	45.4396	30.2286	30.8079	1.452E+10

Block 2. Optimal regimes for obtaining of maximal strength on the face

Setting limitations: y1>49; y2>45; y3<35

X1	X2	X3	Y1	Y2	Y3	Y4

25	1.8	17	49.1088	36.9836	32.2504	5.403E+10
25	1.9	15	49.0355	40.6119	33.2884	5.502E+10
25	1.9	16	49.1392	40.9733	33.3733	5.493E+10
25	1.9	17	49.2429	41.3346	33.4583	5.485E+10
25	2	11	49.0016	44.0235	33.8681	5.523E+10
25	2	12	49.0316	44.3925	34.0031	5.531E+10
25	2	13	49.0616	44.7615	34.1381	5.538E+10
25	2	14	49.0916	45.1305	34.2731	5.546E+10
25	2	15	49.1216	45.4995	34.4081	5.554E+10
25	2	16	49.1516	45.8685	34.5431	5.562E+10
25	2	17	49.1816	46.2375	34.6781	5.57E+10

Block 3. Optimal regimes for obtaining of maximal strength on the sieve

Setting limitations: y1>47; y2>43; y3<35

X1	X2	X3	Y1	Y2	Y3	Y4
25	2	9	48.9416	43.2855	33.5981	5.507E+10
25	2	10	48.9716	43.6545	33.7331	5.515E+10
25	2	11	49.0016	44.0235	33.8681	5.523E+10
25	2	12	49.0316	44.3925	34.0031	5.531E+10
25	2	13	49.0616	44.7615	34.1381	5.538E+10
25	2	14	49.0916	45.1305	34.2731	5.546E+10
25	2	15	49.1216	45.4995	34.4081	5.554E+10
25	2	16	49.1516	45.8685	34.5431	5.562E+10
25	2	17	49.1816	46.2375	34.6781	5.570E+10

Блок 4. Optimal regimes for obtaining of maximal strength on the face and on sieve

Setting limitations: y1>49; y2>45; y3<35

X1	X2	X3	Y1	Y2	Y3	Y4
25	2	14	49.0916	45.1305	34.2731	5.546E+10
25	2	15	49.1216	45.4995	34.4081	5.554E+10
25	2	16	49.1516	45.8685	34.5431	5.562E+10
25	2	17	49.1816	46.2375	34.6781	5.570E+10

Block 5. Optimal regimes for obtaining of minimal R:

Setting limitations: y1>30; y2>20; y3<37.

X1	X2	X3	Y1	Y2	Y3	Y4x
43	2	7	45.0917	27.4934	30.8597	9.096E+09
43	2	8	44.4042	27.2673	31.2021	9.329E+09
43	2	9	43.7167	27.0411	31.5446	9.568E+09
43	2	10	43.0292	26.815	31.887	9.813E+09
45	1.9	7	44.3769	24.0676	29.9863	9.534E+09
45	1.9	8	43.6834	23.7677	30.3017	9.776E+09
45	2	7	44.9301	27.0735	31.2231	8.090E+09
45	2	8	44.1629	26.7813	31.5886	8.320E+09
45	2	9	43.3956	26.489	31.9541	8.555E+09
45	2	10	42.6284	26.1968	32.3196	8.798E+09
45	2	11	41.8611	25.9045	32.6851	9.047E+09
45	2	12	41.0939	25.6123	33.0506	9.303E+09
45	2	13	40.3266	25.32	33.4161	9.567E+09
45	2	14	39.5594	25.0278	33.7816	9.838E+09

43	2	7	45.0917	27.4934	30.8597	9.096E+09
43	2	8	44.4042	27.2673	31.2021	9.329E+09
43	2	9	43.7167	27.0411	31.5446	9.568E+09
43	2	10	43.0292	26.815	31.887	9.813E+09
45	1.9	7	44.3769	24.0676	29.9863	9.534E+09
45	1.9	8	43.6834	23.7677	30.3017	9.776E+09
45	2	7	44.9301	27.0735	31.2231	8.090E+09
45	2	8	44.1629	26.7813	31.5886	8.320E+09
45	2	9	43.3956	26.489	31.9541	8.555E+09
45	2	10	42.6284	26.1968	32.3196	8.798E+09
45	2	11	41.8611	25.9045	32.6851	9.047E+09
45	2	12	41.0939	25.6123	33.0506	9.303E+09
45	2	13	40.3266	25.32	33.4161	9.567E+09
45	2	14	39.5594	25.0278	33.7816	9.838E+09

x – The volume electric resistance of non modified samples is from 6,6429E+11 to 8,9316E+11

The recommended conditions and parameters for achievement of maximal results are specified on the basis of data for the optimal regimes (blocks 1 to 5).

For minimal swelling (block 1) the recommended conditions and parameters are:

Additive for modification: (29 %);

- mole proportion: $CuSO_4\,5H_2O$: $Na_2S_2O_3\,5H_2O$ (1:2);

– duration of staying before pressing: (7 min.).

For maximal strength on the face (block 2) the recommended conditions and parameters are: 25 %; 1:2; 17 min.;

For maximal strength on the sieve (block 3) the recommended conditions and parameters are: 25 %; 1:2; 9 min.;

For maximal strength on the face and on the sieve (block 4) the recommended conditions and parameters are: 25 %; 1:2; 14 min.;

For minimal electric resistance R (block 5) the recommended conditions and parameters are: 45 %; 1:2;7min.

4. CONCLUSION

On the basis of present study, connected with obtaining and investigation of new cupper sulfide modified nanocomposite wood fibrous materials for electromagnetic wave protection and mathematic modeling and optimization of process, using phenol formaldehyde resin CFS) as bonding substance, it is possible to given the fowling conclusions:

- It is established the advisability for conduction of modification of wood fibers by a surface treatment with $CuSO_4\,5H_2O$ and $Na_2S_2O_3\,5H_2O$ on the stages - gluing and formation of wood fibrous carpet;
- The developed modification method minimizes wastage of reagents and in the same time ensures the possibility for a full modification process;
- Optimal regimes for modification depending on special requirements of different applications of new cupper – sulfide modified nanocomposite wood-fibrous materials have been developed.

The cupper sulfide modified nanocomposite wood-fibrous materials on the basis of phenol formaldehyde resin as bonding substance with improved electroconductivity and corresponding microwave absorption ability at high content of wood component for special applications in the engineering and the popular costumes have been obtained.

The authors acknowledge a favor to Fund „Researches", Ministry of Education, Science and Youth, for the financial support rendered in carrying out the present investigations.

REFERENCES

Bissessur, R., Schindler, J., Kannewurf, C., and Kanatzidis, M. (1993). "Encapsulation of polymers into MoS2 and metal to insulator transition in metastable MoS2," J. Chem. Soc. Chem. Commun. 1582-1585.

Chen, Y.-H., Huang, C.-Y., and Lai, F.-D. (2009). "Electroless deposition of the sulfide coating on polyacrylonitrile with a chelating agent of triethanolamine and its EMI shielding effectiveness," Thin Solid Films 517, 4984-4988.

Chen, Y.-H., Huang, C.-Y., and Lai, F-D. (2010). "The copper sulfide coating on polyacrylonitrile with a chelating agent ethylenediaminetetraacetic acid by an electroless deposition method and its EMI shielding effectiveness," Journal of Applied Polymer Science 115, 570-578.

Floriano, P., Noble, C., Schoonmaker, J., Poliakoff, E., and McCarley, R. (2001). "Cu(0) nanoclusters derived from poly(propylene imine) dendrimer complexes of Cu(II)," 123, 10545-10553.

Grohn, F., Kim, G., Bauer, B., and Amis, E. (2001). "Nanoparticle formation within dendrimer-containing polymer networks: Route to new organic−inorganic hybrid materials," Makromolecules 34, 2179-2185.

Hearshaw, M., and Moss, J. (1999). "Organometallic and related metal-containing dendrimers," Chem. Commun. 1, 1-8.

Kozlevcar, B., and Music, B. (2005). "Copper (II) complexes with lignin model compound vanillin," Acta Chim. Slov. 52, 40-43.

Lekova, V., Popov, V., Ivanov, B., and Garvanska, R. (1998). "Preparation, characterisation and application of an electroconductive polymeric pigment with microwave absorption properties," Fibers and Textile 6, 52-56.

Liu, Y.-J. (1995). "Postintercalative polymerization of aniline and its derivatives in layered metal phosphates," Chem. Mater. 7, 1525-1533.

Liu, Y.-J. (1993). "Intercalation of water-soluble polymers in V2O5 xerogel," Advanced Materials 5(5), 369-372.

Pomagailo, A., Rozenberg, A., and Ufljand I. (2000). Metal Nanoparticles in Polymers, Chemistry, Moskow, 672 pp.

Sun, Y., and Xia Y. (2002). "Shape-controlled synthesis of gold and silver nanoparticles," Science 298, 2176-2179.

Wang, L., Brazis, P., Rocci, M., Kannewurf, C., and Kanatzidis, M. (1998). "α -$RuCl_3$: A new host for polymer intercalation. Lamellar polymer/$RuCl_3$ nanocomposites," Mat. Res. Soc. Sympl. Proc. 519, 257-264.

Wang, L., Rocci-Lan, M., Brazis, P., Kannewurf, C., Kim,Y., Lee,W., Choy, J., and Kanatzidis, M. (2000). "α -RuCl3/polymer nanocomposites: The first group of intercalative nanocomposites with transition-metal-halides," J. Amer. Chem. Soc. 122, 6629-6640.

Wu, C., Kanatzidis, M., Marcy, H., DeGroot, D., and Kannewurf, C. (1989a). "Conductive-polymer intercalation in layered V2O5 xerogels. Intercalated polypyrrole," Polym. Mat. Sci. Eng. 6, 969-973.

Wu, C., Marcy, H., and Kannewurf, C. (1989b). "Conductive polymer bronzes. Intercalated polyaniline in V_2O_5 xerogels," J. Amer. Chem. Soc. 111, 4139-4141.

Zend, F., and Zimerman, S. (1997). "Dendrimers in supramolecular chemistry: From molecular recognition to self-assembly," Chem. Rev. 97, 1681-1712.

Zhang, J., and Kamdem, D. P. (2000). "FTIR characterization of copper ethanolamine - Wood interaction for wood preservation," Holzforschung 54, 119-122.