Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2003
Volume 6
Issue 2
Series WOOD TECHNOLOGY

Copyright © Wydawnictwo Akademii Rolniczej we Wroclawiu, ISSN 1505-0297
DZIURKA D., ŁĘCKA J., MIRSKI R. 2003. THE EFFECT OF GRAFTING PARTICLES WITH ACETOACETYL GROUPS ON THE PROPERTIES OF PARTICLEBOARDS **Electronic Journal of Polish Agricultural Universities**, Wood Technology, Volume 6, Issue 2.
Available Online http://www.ejpau.media.pl

THE EFFECT OF GRAFTING PARTICLES WITH ACETOACETYL GROUPS ON THE PROPERTIES OF PARTICLEBOARDS

Dorota Dziurka, Janina Łęcka, Radosław Mirski
Department of Wood–Based Materials, The August Cieszkowski Agricultural University of Poznań, Poland

ABSTRACT
INTRODUCTION
MATERIAL AND METHODS
DISCUSSION OF RESULTS
CONCLUSIONS
REFERENCES

ABSTRACT

The aim of the study was to investigate the acetoacetylation of particles on the formaldehyde content and the physical and mechanical properties of particleboards, glued with the UF resin. The produced particleboards were subjected to the following tests: internal bond, modulus of rupture, modulus of elasticity, swelling in thickness after 24 hours of soaking in water, the content and the emission of formaldehyde. Results of the study make it possible to state that spreading ethyl acetoacetate on the particles before gluing, results in the decrease in the content as well as the emission of formaldehyde from particleboards, without causing essential changes in their physical and mechanical properties.

Key words: UF resin, particleboards, acetoacetyl groups

INTRODUCTION

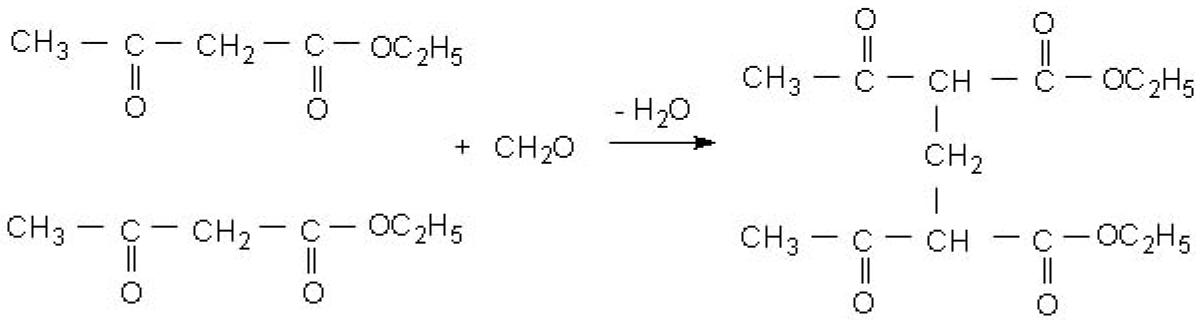
The properties of particleboards greatly depend on the kind of bonding agents used in their production. Currently, about 90% of the world production of particleboards is manufactured with the use of urea-formaldehyde (UF) resins [1], mainly because of their relatively low price, good technological properties, absence of colour in cured polymers and easy adaptability to a variety of curing conditions [2]. However, among the disadvantages of this kind of boards there are the free formaldehyde content and low resistance to changeable environmental conditions; these factors considerably limit the range of UF resin uses.

Although the results of contemporary studies on the hygienic properties of particleboards make it possible to reduce the formaldehyde emission by 80-90% [3], researchers still have not succeeded in increasing the water resistance or improving the mechanical properties of the boards. The need for expanding the use range of the boards, as well as increasing demands concerning further reduction of formaldehyde emission lead to the intensification of research aiming at improving properties of particleboards by means of modifying UF resin. The modification of UF resins is supposed to make it possible to produce resins that meet the above requirements.

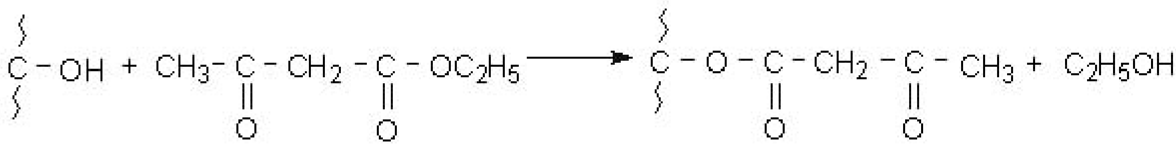
The researches done so far prove that the improvement of strength properties of particleboards can be obtained by introducing into UF resins such substances as furfuryl alcohol [4, 5, 6], resorcinol [7, 8, 9], melamine [8, 10, 11], diisocyanate (PMDI) [12, 13, 14, 15], urea [16, 17, 18], and succinaldehyde [19]. Moreover, the hardening agents also affect the strength properties of particleboards [13].

However, compounds introduced into UF resins may cause a disturbance of the polycondensation process, due to the reaction of hydroxymethylene groups, resulting in the deterioration of the properties of particleboards. Therefore, the methods of modification of the wood surface designed for the production of particleboards are becoming increasingly important. Acetylation is the most investigated of all chemical modification treatments. It is known that the reaction of the hydroxyl groups of cellulose, hemicellulose and lignin with acetic anhydride can acetylate wood. Acetylation of both solid wood and wood composite has the generally advantageous effect of decreasing the hydroscopicity of wood cell-wall material [20]; one hydroxyl group is blocked for each acetyl group with which it reacts. Thickness swelling in flakeboards and particleboards could be reduced by 80-90% by the acetylation of the furnish before board production [21, 22]. Acetylation may consequently, however, also decrease the number of hydrogen bonds formed between wood and adhesives and thereby interfere with the adhesion process, which is all-important in the manufacturing of wood-based composites. It is reasonable to expect that a reduced availability of hydroxyl groups may decrease bond strength development rates, as well as final bond strength. Acetylation may impair the hydrophilic nature of the wood substrate, reduce its wettability, and thus lead to poor adhesive penetration and bonding [23]. Chow et al. [24] observed that the mechanical properties of hardboards produced from acetylated fibers with a resol phenol-formaldehyde adhesive were lower than those of panels produced from normal fibers without acetylation. The strength of fully cured panel products made with resol PF or isocyanate adhesive is already known to be somewhat reduced by acetylation [24, 25, 26].

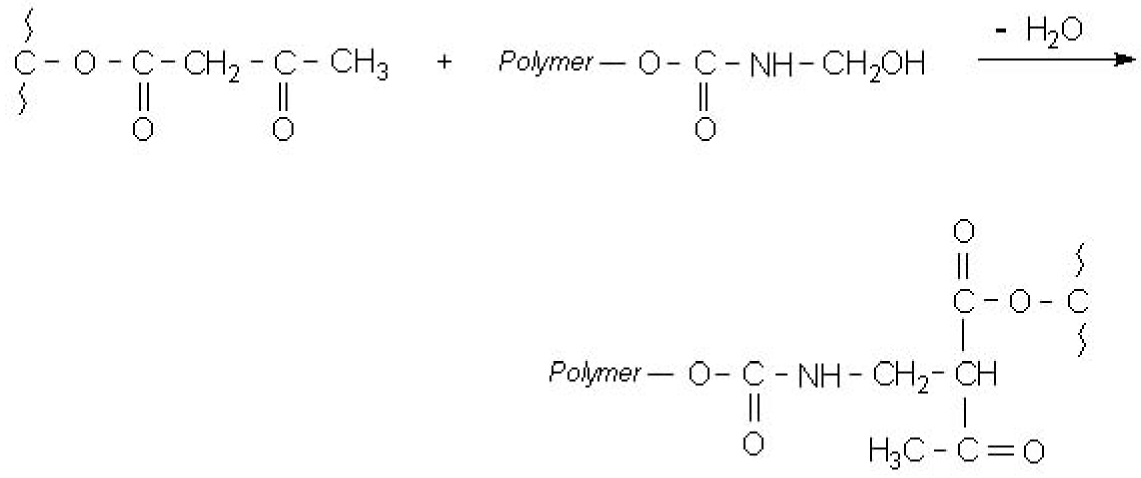
The application of ethyl acetoacetate for the modification of particles used for the particleboard production may turn out worthwhile. This compound, besides the reaction with free formaldehyde (1):



should also react with hydroxyl groups of the wood components (cellulose, lignin) (2):



It is assumed that it may be possible to obtain the reinforcement of glue-wood bonds due to the formation of the covalent bond according to the reaction (3):



As a consequence, an improvement of the physical and mechanical properties of particleboards is expected.

The aim of the study was to investigate the effect of the acetoacetylation of particles on the formaldehyde content and the physical and mechanical properties of particleboards, glued with the UF resin.

MATERIAL AND METHODS

The applied materials

Pure urea-formaldehyde resin, designed for use in the production of particleboards, was applied for experimental purposes. The used UF resin was manufactured by Zakłady Azotowe Kędzierzyn S.A., Poland.

Scotch pine (*Pinus sylvestris* L.) particles obtained under industry conditions were used to produce particleboards. The particles, before being applied to the production of particleboards, underwent screen classification: dust and the fraction unable to get through square mesh (2 mm on a side) were removed. In order to prevent the possible decomposition of ethyl acetoacetate by the water action, the used particles were dried at the temperature of 105°C to the constant mass. Some of the particles were ground in a vibratory ball mill; the obtained dust was used in preparing samples used in the infrared spectral investigations.

Ethyl acetoacetate (CH_3-CO-CH_2CO-OC_2H_5) was purchased from Sigma-Aldrich, Germany, ammonium chloride (NH_4Cl) was purchased from Polskie Odczynniki Chemiczne, Gliwice, Poland. All chemicals were used as received.

The graft of particles with acetoacetyl groups

Ester was spread onto the dry particles in the quantities of 5%, 10%, 15%, 20% and 25% in respect to the dry mass of particles. Particles prepared in such a way were exposed to the temperature of 180°C between shelves of the press for 30 min. It was assumed that in this time the reaction of cellulose estrification would occur. Besides that, in order to determine in which way the temperature and its time of action on the particles treated with ethyl acetoacetate affect formaldehyde emission and strength properties, the particles on which ester was spread in the quantity of 15% were used for the production of particleboards without carrying the reaction of estrification between shelves of the press, and additionally they were subjected to the action of the raised temperature for 60 min.

FTIR spectroscopic study of modified wood and cured resin structures

FTIR spectroscopy was used to explain the effect of ethyl acetoacetate on the wood substance, the structure of the cured resin, and the character of interactions between the wood and resin. An IR spectrum is a very characteristic feature of a substance and therefore it can be treated as an analytic tool for identifying structural groups present in the investigated compounds, as well as for studying the occurring chemical processes. The analyses were made for pine wood and urea resin before and after the activation with ethyl acetoacetate. The samples for IR spectral investigations were prepared according to the following procedures:

- the control UF resin system and the ethyl acetoacetate-added UF resin system (25 parts by weight of ethyl acetoacetate per 100 parts by weight of dry resin solids) were heated in glass tubes at 100°C until the resin systems gelled.
- the control wood dust system and the ethyl acetoacetate-added wood dust system (50 parts by weight of ethyl acetoacetate per 100 parts by weight of dry wood dust) were heated at 180°C and kept at that temperature for 30 min.

Moreover, the samples intended for FTIR determination were ground in a vibratory ball mill and later dried under vacuum in the presence of P_2O_5. IR spectra were obtained with the use of the potassium bromide tablet method and the Mattson Infinity FTIR spectrophotometer (MATTSON INSTRUMENTS).

The production of laboratory particleboards and the examination of their properties

In order to examine the effect of particles grafted with acetoacetyl groups on the properties of particleboards glued with UF resin, single-layer boards with the density of 700 kg/m^3 and dimensions of 500 x 600 x 12 mm were produced under laboratory conditions. The following pressing parameters were employed: pressure 2.5 MPa, temperature 180°C, time 5 minutes. Their resin content was 10% by oven dry wood weight. Ethyl acetoacetate was spread on the particles before gluing in the amounts of 5, 10, 15, 20 and 25% in relation to dry wood. Urea resin was spread over the modified particles in a slow-speed laboratory blender.

The used curing agent was 20% solution of ammonium chloride in the amount of 2% in relation to dry resin solids.

The properties of the particleboards were examined according to the relevant European Standards (EN):

- modulus of rupture (MOR) and modulus of elasticity (MOE) according to EN 310: 1993 “Wood-based panels – Determination of modulus of elasticity in bending and of bending strength”
- internal bond (IB) according to EN 319: 1993 “Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the boards”
- swelling in thickness after 24 hours according to EN 317: 1993 “Particleboards and fibreboards – Determination of swelling in thickness after immersion in water”
- formaldehyde content according to EN 120: 1994 “Wood-based panels – Determination of formaldehyde content – Extraction method called the perforator method”
- formaldehyde emission according to PN-F-06106-2: 1994 “Furniture and materials for furniture production – Methods of determination of toxic substances – Determination of formaldehyde release by the chamber test method.

DISCUSSION OF RESULTS

Results of studies on particleboard properties

The effect of the method of the particle acetoacetylation on the properties of particleboards produced with their use is presented in Table 1. It is worth stressing that it is necessary to dry the particles before the ester spreading. No satisfactory quality of the particleboards could be obtained in case of the treatment with ethyl acetoacetate of air-dried particles (moisture content 4.5%). All boards were delaminated as a result of the creation of gaseous substances in the process of pressing, whereas the particleboards produced with the particles subjected to the desiccation did not undergo delamination. However, in this case the time of the action of high temperature turned out to be important. The conducted investigations prove that the properties of particleboards produced without prior heating at the temperature of 180°C after the treatment of particles with the ester were characterized by considerably lower physical and mechanical properties. The properties of particleboards, produced from particles non-modified and subjected to the action of the temperature of 180°C for 60 min. after spreading the ester on them, were similar. The boards exhibiting the best properties were obtained when the particles with ethyl acetoacetate spread on them were heated at the temperature of 180°C for 30 min.

Table 1. The effect of the time of the particle acetoacetylation on particleboard properties

Amount of ethyl acetoacetate applied on particles	Time of temperature action	IB	MOR	MOE	Swelling in thickness after 24 h
%	min	MPa	MPa	MPa	%
0	0	0.55	14.9	2230	45.7
15*	30	-	-	-	-
15	0	0.22	12.2	2000	52.3
15	30	0.66	17.2	1901	38.2
15	60	0.54	12.6	1750	40.2

* The particleboard, produced with particles not subjected to drying before the ethyl acetoacetate spreading, delaminated.

The effect of the time of particle acetoacetylation at the temperature of 180°C, on the effectiveness of limiting formaldehyde content in the board is illustrated in Figure 1. As can be seen from the figure, the formaldehyde content in the board increases along with the increase in the time of action of the raised temperature. It may be explained by the fact that with the longer time of action of high temperature two parallel processes occur: a partial decomposition of acetoacetyl groups and their reaction with copolymers of wood, which in effect limits their ability for the reaction with free formaldehyde (reaction 1).

The results presented in Figure 2 concern the carried out parallel investigations of the effect of the time of particle acetoacetylation on the emission of formaldehyde, determined by the chamber test method. Also in that case the lengthening of the heating time of particles with ethyl acetoacetate does not increase the effectiveness of limiting formaldehyde emission.

Fig. 1. The effect of the heating time of particles treated with ethyl acetoacetate on formaldehyde content in particleboards

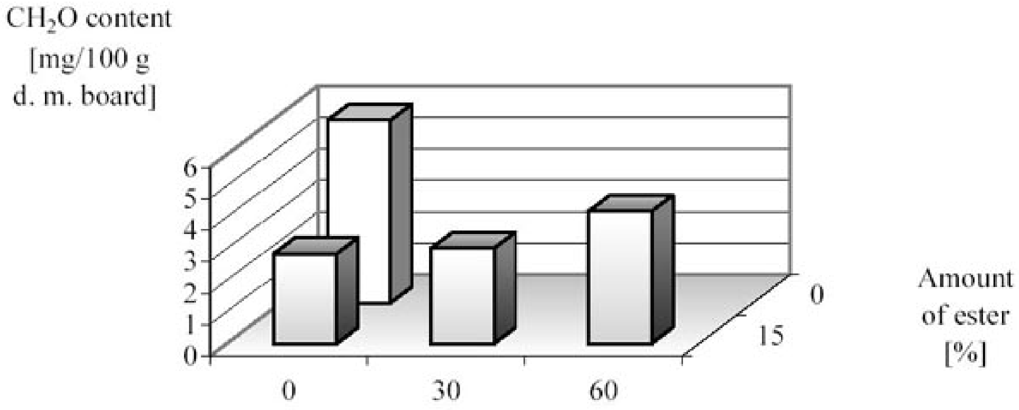
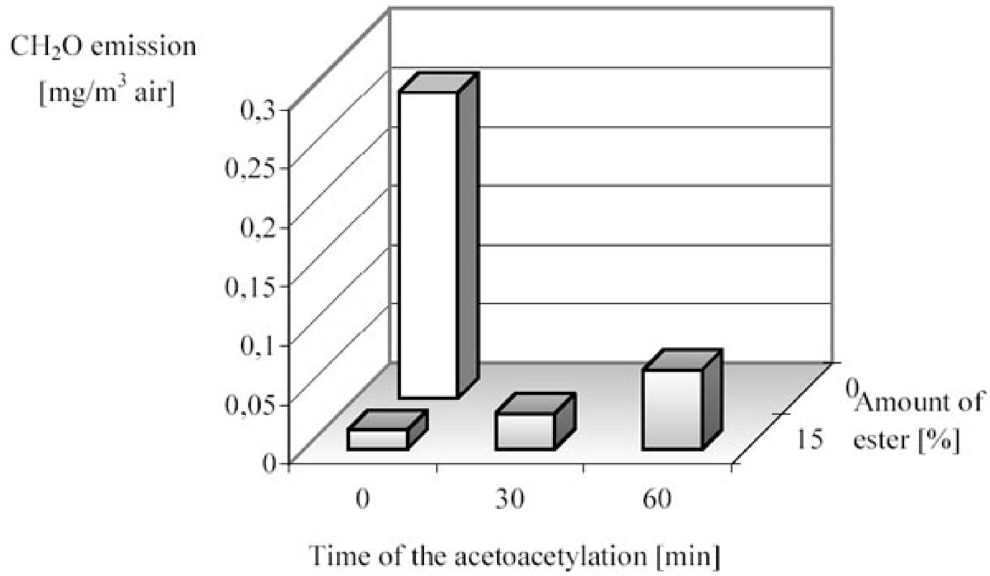


Fig. 2. The effect of the heating time of particles treated with ethyl acetoacetate on formaldehyde emission from particleboards



Considering that boards with the best physical and mechanical properties and a considerably limited formaldehyde content may be obtained in the case when the particles with ethyl acetoacetate spread on them were heated at the temperature of 180°C for 30 min., it was therefore decided to carry out in these conditions further studies on the effect of the degree of the particle acetoacetylation on the particleboard properties.

The effect of the amount of ethyl acetoacetate on the particles on the properties of particleboards is shown in Table 2. The included data indicate that the increase of the ester spread on the particles from 5% to 10% does not significantly affect the mechanical properties of particleboards. The best properties were obtained when the amount of ethyl acetoacetate was 15%. In this case the increase in IB by 33%, MOR by 15%, and the decrease in swelling in thickness by 16% were observed. Further growth in the amount of the ester spread on the particles results in a decrease in the strength properties of particleboards; at the same time the hydrophobic properties increase being expressed by the decrease in the swelling in thickness after 24 hours. It is supposed, as the amount of the ester spread on the particles grows up to 20%, that the amount of the ester that does not react with the wood increases. Therefore, the non-reacted ethyl acetoacetate may react with the UF resin during the pressing of particleboards, disturbing its further polycondensation. Hence, the increase of the hydrophobic properties of particleboards caused by the decrease of the hydroxyl groups both in the wood and in the resin was observed; on the other hand the reduction of the level of the strength particleboard properties takes place, caused by the decrease of the polycondensation degree of the UF resin. Additionally, it is also probably caused by the greater acetoacetylation of the hydroxyl groups of wood components and simultaneously the decrease in the amounts of these groups in the resin. Consequently, fewer resin-wood bonds are formed. The results of the formaldehyde content confirm these expectations. The greater the amount of the applied ester the better results are achieved. The decrease in the formaldehyde content is due to the reactions of ethyl acetoacetate (reaction 1) and hydroxymethylene groups of the resin with free formaldehyde [27, 28]. What is more, applying ethyl acetoacetate on the particles in the amount of 15% limits the formaldehyde content to the value that characterizes some natural wood species [29, 30, 31].

Table 2. The effect of the amount of the ethyl acetoacetate spread on particles on the properties of particleboards

Amount of ethyl acetoacetate applied on particles	IB	MOR	MOE	Swelling in thickness after 24 h	CH_2O content
%	MPa	MPa	MPa	%	mg/100g of board dry mass
0	0.55	14.9	2230	45.7	5.81
5	0.55	15.9	2225	46.9	3.99
10	0.59	15.9	2290	43.6	3.63
15	0.73	17.2	2480	38.2	3.03
20	0.70	16.7	2390	37.2	2.84
25	0.66	15.6	2300	32.5	2.66

The results of FTIR spectroscopy

Figures 3 and 4 show IR spectra of the studied samples. The IR spectra of pine dust before and after the modification indicate that there were considerable changes in the structure of wood treated with ethyl acetoacetate.

In the spectra of wood treated with the ester the intensity of the band at 1738 cm^{-1} increases by 82%. The band at this wavelength is characteristic of the vibrations of a carbonyl group of the ester. The band at 3419 cm^{-1} is attributed to the hydrogen bonds and indicates the presence of the OH groups. Due to the reaction of hydroxyl groups with acetoacetyl groups the possibility of forming the hydrogen bonds decreases, and, as a result, the intensity of this band decreases by 25%. The changes are also observed in the intensity of the band at the wavelength of 1050-1300 cm^{-1}, attributed to the vibrations of the ester group. In this region, the ester band appears at 1260 cm^{-1} that in the spectra of non-modified wood is found only on the slope of the band at 1241 cm^{-1}. Moreover, in the spectra of wood treated with ethyl acetoacetate the intensity of the band at 2930 cm^{-1} decreases by 27%. This band is characteristic for the stretching vibrations of CH bonds of methylene groups of the ester.

Fig. 3. IR spectra of pine dust held at the temperature of 100°C with and without the addition of ethyl acetoacetate

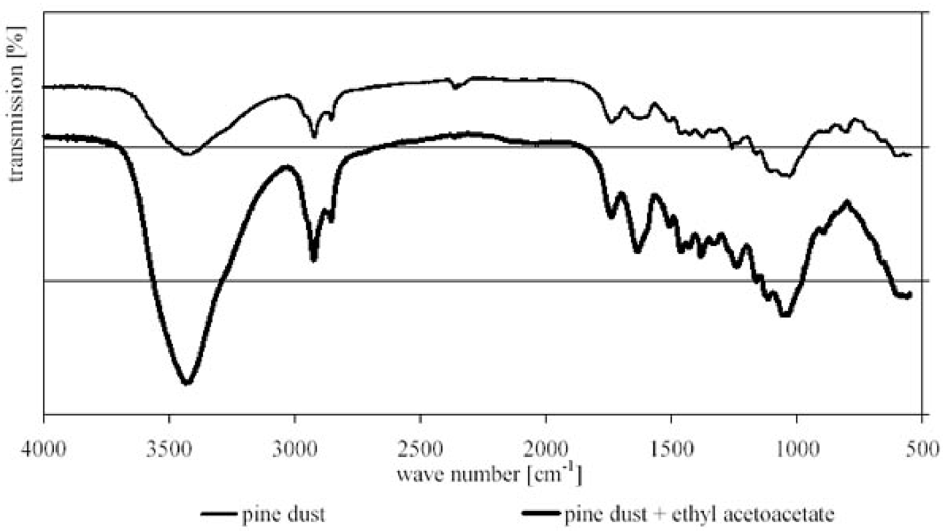
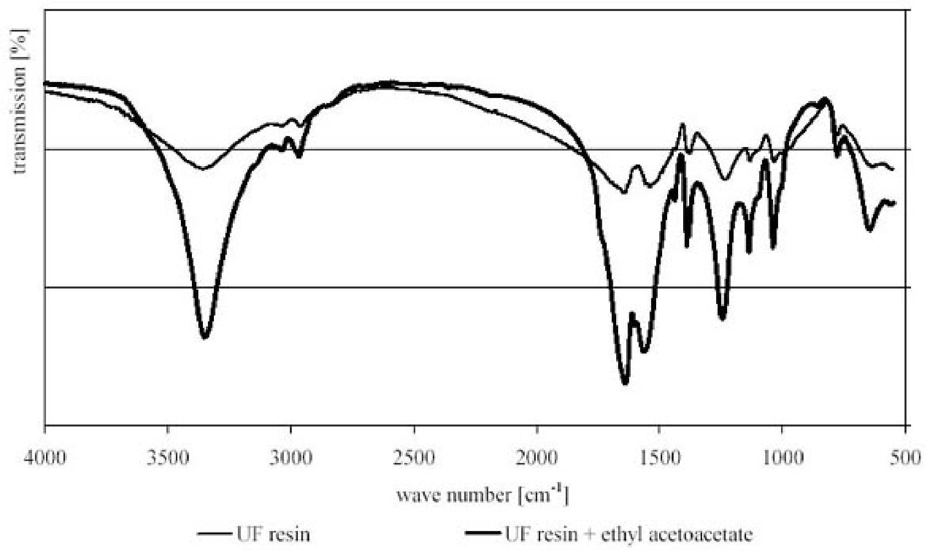


Fig. 4. IR spectra of UF resin cured at the temperature of 100°C with and without the addition of ethyl acetoacetate



The FTIR analysis of the polycondensed UF resin shows that, in the conditions of particleboard production, acetoacetyl groups react with hydroxymethylene groups of UF resin forming ester and ether systems, which is proved by changes in the resin spectra before and after the addition of ethyl acetoacetate. In the spectrum of the UF resin modified with acetoacetyl groups, presented in Figure 3, a shift of the amide band from 1539 cm^{-1} to 1562 cm^{-1} is observed. However, the first amide band (C=O) shifts from 1647 cm^{-1} to 1640 cm^{-1}. The shifts of amide bands prove that there are changes in the polarity of bonds, especially the NH bond, and it may be ascribed to the proposed structure (reaction 3). Important changes are also observed in the intensity of the band at the wavelength of 1035-960 cm^{-1}, attributed to CH_2OH before and after introducing acetoacetyl groups into the resin. In this region, therefore, in the resin spectrum there is a wide band that after the modification with ethyl acetoacetate narrows considerably; simultaneously, on the slope of the first amide bond at 1640 cm^{-1} an absorption band appears which comes from the vibrations of a carbonyl group of the ester. Moreover, the decrease in the relation of the A_{1640}/A_{3351} absorption degree from 0.77 to 0.66 shows that there is also a small decrease in the OH group content in relation to the amount of these groups in UF resin. Supposedly, the reduction of the number of OH groups in the modified resin is caused by their reaction with acetoacetyl groups.

CONCLUSIONS

1. Spreading ethyl acetoacetate on the particles before gluing results in the decrease in the content, as well as the emission of formaldehyde from particleboards.
2. Introducing ethyl acetoacetate in the amounts above 15%, in respect to dry weight wood, results in the decrease of physical and mechanical properties of particleboards.
3. The FTIR studies of acetoacetylated particles and resin prove that acetoacetyl groups react with hydroxymethylene groups of both wood composites and resin, forming ester or ether systems.
4. The results of the studies lead to the conclusion that boards with the best physical and mechanical properties and considerably limited formaldehyde contents may be obtained in the case when particles were grafted with ethyl acetoacetate in the amount of 15%.

REFERENCES

1. Sellers Jr. T., 1992. Wood adhesives market builds a promising future on a profitable past. Adhäsion Age. 35(10), 22-25.
2. Pizzi A., 1994. Advanced wood adhesives technology. Marcel Dekker Inc. New York.
3. Pizzi A., 1989. Wood adhesives. Chemistry and technology. Release of formaldehyde by wood products. Marcel Dekker Inc. New York.
4. Schultz T. P., 1990. Exterior plywood resin formulated from furfuryl alcohol and para-formaldehyde. Holzforschung 44, 467-468.
5. Schneider M. H., Chui Y. H., Ganev S. B., 1996. Properties of particleboard made with a polyfurfuryl-alcohol/urea-formaldehyde adhesive. For. Prod. J. 46(9), 79-83.

6. Kim M. G., Wasson L., Burris M., Wu Y., Watt Ch., Strickland R. C., 1998: Furfuryl alcohol emulsion resins as co-binders for urea-formaldehyde resin-bonded particleboards. Wood and Fiber Science. 30(3): 238-239.
7. Roffael E., 1980, Modifizierung von Harnstofformaldehydharzen mit Resorcin [Modification of UF resin with resorcinol]. Adhäsion. 24, 422-424 [in German].
8. Roffael E., Dix B., Miertzsch H., Schwarz T., Kehr E., Scheithauer M., Hoferichter E., 1993. Feuchtebeständigkeit und Hydrolyseresistanz von Holz-zuHolz-Bindungen in Spanplatten, hergestellt mit formaldehydarmen modifizierten Harnstoff-Formaldehydarzen unter Einsatz verschiedener Härtungsbeschleunigersystem. Teil 1: Eigenschaften von unmodifizierten und modifizierten Harnstoff-Formaldehydarzen (UF-Harze) [Moisture and resistance of particleboards, bonded with unmodified and modified low formaldehyde UF-resin using different catalyst systems. Part 1: Properties of unmodified and modified UF resin]. Holz Roh. Werkstoff. 51, 197-207 [in German].
9. Łęcka J., Morze Z., M. Sedliačik M., 1995. Effect of the modification urea resin with the resorcine and its alkyloderivatives upon properties of particle boards. 12th Sympózium "Pokroky vo výrobe a použití lepidiel v drevárskom priemysle". Zvolen. Zb. ref. 48–57.
10. Wittman O., 1983. Herstellung von Spanplatten mit verstärkten Aminoplast-Leimhärzen [Production of particleboards with reinforced amino resins]. Holz Roh. Werkstoff. 10, 431-435 [in German].
11. Mercer T. A., Pizzi A., 1994. Condensation on the principles of preparation of melamine-urea-formaldehyde resins for particleboards. Holzforsch. Holzverwert. 46(3), 51-54.
12. Kehr E., Scheithauer M., Hoferichter E., 1993. Feuchtebeständigkeit und Hydrolyseresistanz von Holz-zu-Holzbindungen in Spanplatten, hergestellt mit formaldehydarmen modifizierten Harnstoff-Formaldehydarzen unter Einsatz verschiedener Hartungsbeschleunigersystem. Teil 2: Herstellung und Eigenschaften von mit unmodifizierten Harnstoff-Formaldehydharzen (UF-Harze) hergestellten Spanplatten [Moisture and resistance of particleboards, bonded with unmodified and modified low formaldehyde UF-resin using different catalyst systems. Part 2: Preparation and properties of particleboards bonded with unmodified low formaldehyde resins]. Holz Roh. Werkstoff. 51(6), 365-372 [in German].
13. Kehr E., Riehl G., Hoferichter E., Roffael E., Dix B., 1994. Moisture and hydrolysis resistance of particleboards, bonded with unmodified and modified low formaldehyde UF-resins using different catalyst systems. Part 3: Properties of particleboards bonded with modified low-formaldehyde resins. Holz Roh. Werkstoff. 52, 253-260.
14. Roffael E., Dix B, Kehr E., 1995. Moisture and hydrolysis resistance of wood-to-wood bonds in particleboards manufactured with low-formaldehyde UF resins using various catalyst systems. Part 4: Some chemical properties of particleboards bonded with unmodified and modified UF-resins. Holz Roh. Werkstoff. 53(5), 315-320.
15. Deppe H. J., 1977. Technische Fortschritte bei der Isocyanatverleimung von Holzspanplatten [Technical progress in the production of particleboards bonded with isocyanate resins]. Holz Roh. Werkstoff. 8, 295-302 [in German].
16. Sellers Jr. T., Miller G. D., Li-Shih Nieh, W., 1990. Evaluation of post-added ester and/or urea as a formaldehyde scavenger in UF resins used to bond southern pine particleboard. For. Prod. J. 41 (1), 53-56.
17. Boehme C., 1995. Reducing formaldehyde emission of UF-bonded particleboards using 'blocking layers'. Holz Roh. Werkstoff. 53(4), 237-242.
18. Roffael E., Buchholzer P., 1990. Einfluß eines Formaldehdfängers auf die Eigenschaften von Faser-Span-Platten [Influence of a formaldehyde scavenger on properties of fiber- and particleboards]. Holz Roh. Werkstoff. 48, 384-387 [in German].
19. Wang S., Pizzi A., 1997. Succinaldehyde induced water resistance improvements of UF wood adhesives. Holz Roh. Werkstoff. 55, 9-12.
20. Rowell R. M. 1982. Distribution of acetyl groups in southern pine reacted with acetic anhydride. Wood Sci. 15, 172-182.
21. Rowell R. M., Tillman A. M., Liu, Z., 1986 a. Dimensional stabilization of flakeboard by chemical modification. Wood Sci. Technology, 20, 83-95.
22. Rowell R. M., Tillman A. M., Simonson R., 1986 b. A simplified procedure for the acetylation of hardwood and softwood flakes for flakeboard production. J. Wood Technol. 6(3), 427-448.
23. Rowell R. M., Banks W. B., 1987. Tensil strength and toughnesss of acetylated pine and lime flakes. Brit. Polymer J., 19, 478-482.
24. Chow P., Bao Z., Youngquist J. A., Rowell R. M., Muehl J. H., Krzysik A. M., 1996. Properties of hardboard made from acetylated aspen and southern pine. Wood Fiber Sci. 28(2), 252-258.
25. Youngquist J. A., Rowell R. M., 1986. Mechanical properties and dimensional stability of acetylated aspen flakeboard. Holz Roh. Werkstoff. 44, 453-457.
26. Rowell R. M., Imamura Y., Kawai S., Norimoto M., 1989. Dimensional stability, decay resistance, and mechanical properties of veneer-faced low-density particleboards made from acetylated wood. Wood Fiber Sci. 21(1), 67-79.
27. Del Rector F, Blount W.W., Leonard D.R., 1989. Applications for acetoacetyl chemistry in thermoset coatings. J. Coatings Technol. 61(771), 31–37.
28. Witzeman J. S., Crain A. L., Clemens R. J., 1992. Thermosetting coating compositions. PCT WO 92/21646.
29. Meyer B., Boehme Ch., 1997. Formaldehyde emission from solid wood. For. Prod. J.. 47(5), 45–48.
30. Roffael E., Mehlhorn L., 1980. Einfluss der Randbedingungen bei der Bestimmung des extrahierbaren Formaldehyds in Holzspanplatten nach der Perforatormethode [The effect of the boundary conditions on the content of formaldehyde in the particleboards determined by the perforator method]. Holz Roh. Werkstoff. 3, 85-88 [in German].
31. Tsapuk A. K., 1992. About the possibility of producing wood particleboards with extremely low formaldehyde content. Holz Roh. Werkstoff. 50, 387-388.

Dorota Dziurka, Janina Łęcka, Radosław Mirski
Department of Wood-Based Materials
The August Cieszkowski Agricultural University of Poznań
Wojska Polskiego 38/42, 60-637 Poznań, Poland
e-mail: ddziurka@woodcock.au.poznan.pl

Responses to this article, comments are invited and should be submitted within three months of the publication of the article. If accepted for publication, they will be published in the chapter headed 'Discussions' in each series and hyperlinked to the article.