Influence of press factor and additional thermal treatment on technology for production of eco-friendly MDF based on lignosulfonate adhesives

V. Savov[1*], I. Valchev[2], N. Yavorov[2], K. Sabev[1]

[1] *University of Forestry, 10 Kl. Ohridski Blvd., 1797 Sofia, Bulgaria*
[2] *University of Chemical Technology and Metallurgy, 8 Kl. Ohridski Blvd., 1756 Sofia, Bulgaria*

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A major shortcoming of medium density fibreboards (MDF) as a material for furniture production is the emission of formaldehyde from the boards. To solve the problem of formaldehyde emissions, an especially perspective direction is the use of lignosulfonates as natural adhesives. A major disadvantage of the lignosulfonates compared to the presently used synthetic binders is their lower reactivity. This leads to the need for an extended duration of the hot-pressing and to the worse water-resistance of the panels. This report presents a study on the influence of the duration of hot-pressing and the additional thermal treatment on the properties of eco-friendly MDF. Panels are produced in laboratory conditions with lignosulfonate as adhesive without any formaldehyde-based synthetic binders. Six types of panels were produced with variation of the press factor from 30 to 60 s.mm^{-2} with and without additional thermal treatment. The properties of the obtained boards were compared with values in EN standards and with a control board obtained with 10% urea formaldehyde resin. The obtained panel properties fully satisfy the relevant EN standards on mechanical properties of boards. A comparative analysis was carried out, with corresponding conclusions and recommendations, on the influence of the press factor and the additional thermal treatment on the efficiency of the eco-friendly technology for MDF production based on lignosulfonate adhesives.

Keywords: eco-friendly MDF, lignosulfonate adhesives, press factor, additional thermal treatment

INTRODUCTION

In view of the shortage of large-sized wood raw material [8], the main challenge facing the woodworking industry is the utilization of small-sized, lower-quality wood [4]. One of the main industries using this type of raw material is the production of fibreboards [13]. The production of dry-processed fibreboards is more than 80% of the global production of this type of wood-based panels [23]. In this type of production, as a part of the wood and furniture industry, the issue of environmental friendliness of the production and of the product itself [11] is actual. A major drawback, from an environmental point of view, of the use of urea formaldehyde resins in the industrial production of MDF is the formaldehyde emission from the boards [5]. A major problem for the future development of medium density fibreboards (MDF) technology is the release of formaldehyde from the boards. To the present moment MDF should meet the requirements for Class E_1 formaldehyde emissions, but companies like IKEA have significantly stricter requirements and are in the process of introducing a new class E_0 for formaldehyde emissions.

To reduce the emissions of free formaldehyde in wood-based panels, there are currently four major areas of global concern: reducing the levels of free formaldehyde in resins, while maintaining their adhesive properties [12]; addition of acceptors in order to reduce formaldehyde release from the panels [7]; and use of alternative binders that do not significantly impede the production of panels while maintaining their properties [1].

The latter direction to solve the problem of formaldehyde emissions is the use of so-called green binders, with a view to obtaining eco-friendly boards [2]. Of these binders, wood lignin-based products are the most promising ones [3]. Particularly suitable for binders in the production of MDF, due to the nature of the fiber connections, are lignosulfonates. The latter contain 12 ÷ 19% phenolic OH, ≈16% alcohol OH, ≈3% carbonyl and ≈1% carboxyl groups [6], by which the fiber elements in the panels can be bonded. There have also been a number of successful attempts to obtain, under laboratory conditions, lignosulfonate-based MDFs [9] with partial [14, 15] or complete [11, 16] substitution of synthetic (phenol formaldehyde or urea formaldehyde) resins. A major disadvantage is the relatively large press factor: 60 s.mm^{-1} with partial replacement of phenol formaldehyde and urea formaldehyde resins and 90 s.mm^{-1} in the obtaining of MDF only with the involvement of lignosulfonate as a binder. Previous studies by team members have shown that when using lignosulfonates, hot-pressing temperatures should be above 200 °C [11, 16].

* To whom all correspondence should be sent:
E-mail: victor_savov@ltu.bg

EXPERIMENTAL

For the production of the panels industrially produced wood pulp was used with the following composition: beech - 57%, oak 35%, poplar - 8%. The pulp was dried to a water content of 11%. Bulk density was 29 $kg.m^{-3}$.

As a binder for the experiments magnesium lignosulfonate was used. Lignosulfonates are residues in the production of lignocellulosic fibrous materials by the sulfite method. As a result of the ongoing delignification, lignosulfonates are released, which may be based on Na or Mg. The solution also contains sugars and products from the decomposition of carbohydrates and their concentration after evaporation reaches about 50% dry matter.

The concentration of lignosulfonate used for the experiments was determined by a weight method and was 51.5%. Magnesium content was 6%. The acid factor of the solution was pH 4 ± 1. The content of lignosulfonate in absolutely dry fibres was 15%.

Panels were produced with press factors of 30 $s.mm^{-1}$, 45 $s.mm^{-1}$ and 60 $s.mm^{-1}$ with and without additional thermal treatment. The secondary heat treatment was carried out at a temperature of 160 °C and duration of 45 min.

Blending was carried out on a high-speed (850 rpm) needle blade blender. For hot-pressing a laboratory press type RMC ST 100, Italy, was used. The hot-pressing temperature was 220 °C. The relatively high pressing temperature applied was for the purpose of using an accelerated pressing cycle and because of the high moisture content of the pressed material. The panels were with a set density of 850 $kg.m^{-3}$ (type heavy MDF) and a thickness of 6 mm. Control MDF with 10% urea formaldehyde resin (UFR) content was also manufactured at a press factor of 30 $s.mm^{-1}$ and a hot-pressing temperature of 200 °C. The properties of the panels were determined in accordance with the requirements of the European standards [17-21].

RESULTS AND DISCUSSION

The summarized results for the physical and mechanical properties of the produced MDF are presented in Tables 1 and 2.

The density of MDF varies from 844 to 858 $kg.m^{-3}$, or a deviation of 1.7% is observed in this basic property. Since the deviation is significantly less than the allowed 5%, this main property should not affect the others physical and mechanical properties of the panels and therefore their deviations are due to the change in the studied factors.

Table 1. Physical properties of eco-friendly MDF in dependence of press factor and additional thermal treatment

№	Press factor *c*, $s.mm^{-1}$	Additional thermal treatment *τ*, min	Density *ρ*, $kg.m^{-3}$	Water absorption *A*, %	Swelling in thickness *Gt*, %
1.	30	0	856	135.21	101.06
2.	45	0	850	132.00	77.63
3.	60	0	851	121.34	71.00
4.	30	45	855	123.26	71.77
5.	45	45	847	88.07	44.69
6.	60	45	844	79.55	37.59
Control MDF (with 10% urea formaldehyde resin)					
7.	30	0	858	80.65	35.44

Table 2. Mechanical properties of eco-friendly MDF in dependence of press factor and additional thermal treatment

№	Press factor *c*, $s.mm^{-1}$	Additional thermal treatment *τ*, min	Bending strength *fm*, $N.mm^{-2}$	Modulus of elasticity *Em*, $N.mm^{-2}$
1.	30	0	31.7	3130
2.	45	0	23.1	2610
3.	60	0	15.4	1750
4.	30	45	33.5	3410
5.	45	45	31.5	3540
6.	60	45	25.6	3230
Control MDF (with 10% urea formaldehyde resin)				
7.	30	0	27.2	2280

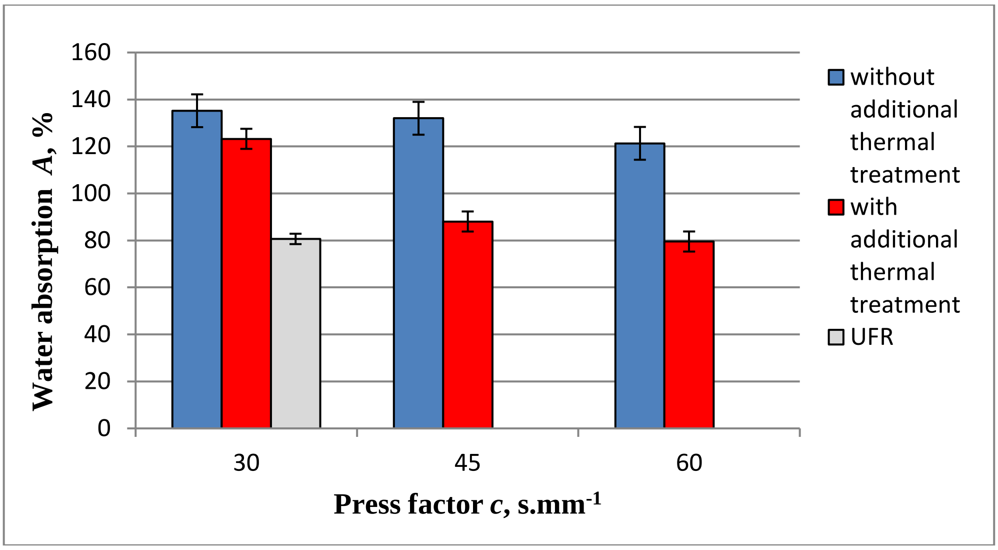

Fig. 1. Water absorption of eco-friendly MDF

In graphic form, the change of the water absorption as a result of the change in press factor and the additional thermal treatment is shown in Figure 1. The chart also shows the value of the control MDF made with urea formaldehyde resin. Under the conditions of the experiment, the water absorption of the obtained eco-friendly MDF varied from 135.2 to 79.6% and the value of the property of the control panels obtained with the urea formaldehyde resin was 80.7%. In general, the panels obtained with lignosulfonate as binder, without additional thermal treatment, exhibit poor water resistance. Of the panels without additional thermal treatment, the MDF obtained at a press factor of 60 s.mm^{-1} was the best, with the smallest values of the water absorption. However, the difference with the worst value of this group of panels at a press factor of 30 s.mm^{-1} was 14% or the improvement in the property with an increase in the press factor from 30 to 60 s.mm^{-1} was only 1.12 times.

The additional thermal treatment had a much stronger influence on the property. At press factors of 45 and 60 s.mm^{-1}, when additional thermal treatment was applied, a significant improvement in the water absorption of the panels was observed. The corresponding improvements in comparison with the MDFs without additional thermal treatment were from 1.53 to 1.5 times.

The MDF obtained at a press factor of 60 s.mm^{-1} and additional thermal treatment had a water absorption value similar to that of the control panel obtained with urea formaldehyde resin. The MDF obtained at a press factor of 30 s.mm^{-1}, despite the additional thermal treatment, displayed high values of water absorption.

In graphic form the change in the swelling of the thickness of the MDF, as a result of the change in press factor and the additional thermal treatment, is shown in Figure 2.

The swelling of the thickness of the MDF obtained with lignosulfonate varied from 101 to 37.6%. This property showed the same tendency as in the case of water absorption - an improvement, respectively a decrease in the values of the property with the increase of the press factor and a significant improvement with the application of additional thermal treatment. In panels without additional thermal treatment, the improvement by increasing the press factor from 30 to 60 s.mm^{-1} was from 101 to 71% or 1.42 times. With the application of additional thermal treatment, the improvement was in the range of 1.88 times, again with a press factor of 60 s.mm^{-1} and additional thermal treatment, the values of the property were similar to those of the control panel obtained with urea formaldehyde resin. In graphical form, the change in bending strength of MDF as a result of the change in the press factor and the additional heat treatment is presented in Fig. 3. The bending strength of the MDFs with lignosulfonate varies from 15.4 to 33.5 N.mm^{-2}. This property, in contrast to the water absorption and swelling in thickness of the panels, shows better, more evident values, with the decrease of the press factor. This can be explained by the relatively high (220° C) hot-pressing temperature, which, with the increased press factor, respectively the increased pressing time, affects the hemicelluloses and cellulosic complexes in the wood, which leads to the fragility (reduced strength) of the panels. However, all panels except those obtained without additional thermal treatment and at a press factor of 60 s.mm^{-1} meet the requirements for general purpose MDF

[22]. The MDF obtained with a press factor of 30 s.mm^{-1}, even without additional thermal treatment, meet the requirements of MDF for load-bearing structures. The additional thermal treatment also gives good results in the bending strength of the panels, with a much greater improvement when the press factor is 45 and 60 s.mm^{-1}. The panels obtained with a press factor of 30 s.mm^{-1} have even better values than the control MDF obtained with urea formaldehyde resin. The results for this property are very encouraging, since the press factor is commensurate with that used in industrial conditions, producing environmentally friendly MDFs with good mechanical strength, which can be used for structural purposes in the manufacture of furniture and others in dry environments. The change in the modulus of elasticity of resulting from the change in the press factor and the additional thermal treatment is presented in graphical form in Fig. 4.

The modulus of elasticity of MDF obtained with lignosulfonate varies from 3540 to 1750 N.mm^{-2}. All panels with the exception of the panel obtained at a press factor of 60 s.mm^{-1} without further thermal treatment, have a modulus of elasticity better than that of the control panel obtained with 10% urea formaldehyde resin. All panels obtained with additional heat treatment meet the most stringent requirements for the property, namely MDF for load-bearing structures.

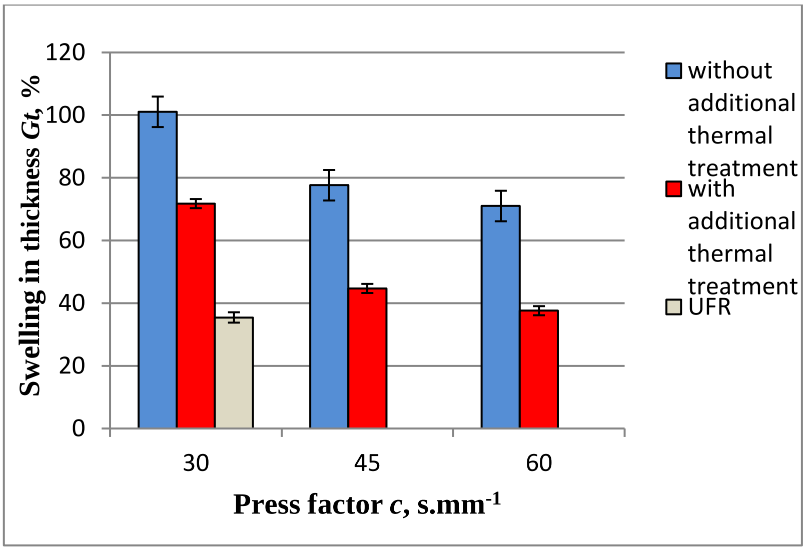

Fig. 2. Swelling in thickness of eco-friendly MDF

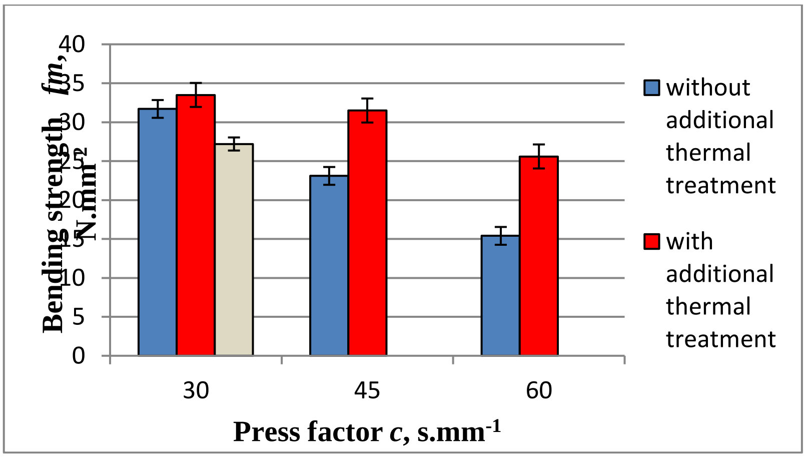

Fig. 3. Bending strength of eco-friendly MDF

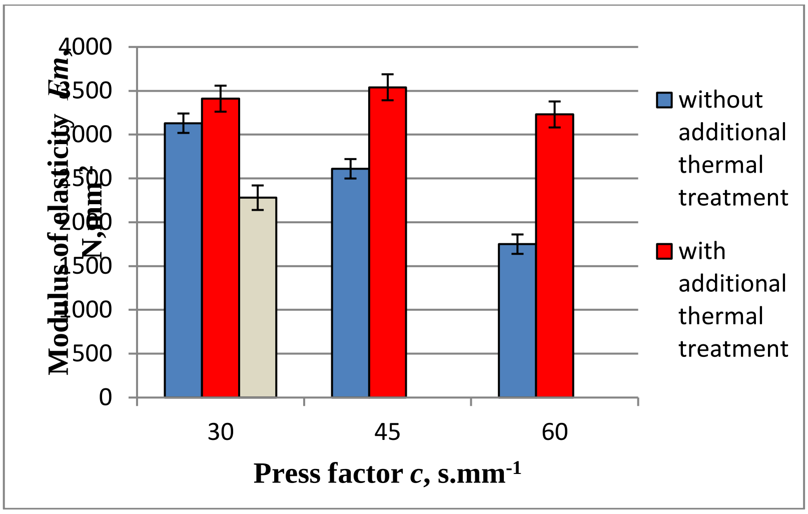

Fig. 4. Modulus of elasticity of eco-friendly MDF

CONCLUSIONS

As a result of the study it was found that eco-friendly MDFs can be successfully produced by applying lignosulfonate adhesives at press factors of hot-pressing similar to industrial ones when urea formaldehyde resins are used.

No significant darkening of the boards was observed as a result of the use of lignosulfonate, their color being similar to that of control MDF produced with urea formaldehyde.

The produced MDFs have mechanical properties similar to, and in some regimes even better than, the control board obtained with 10% urea formaldehyde.

It was found in this study that one of the major disadvantages of using lignosulfonate adhesives in an accelerated cycle of hot-pressing - the water resistance of the boards, can be overcome by applying additional thermal treatment after the hot pressing. By such additional treatment the boards improve by reducing nearly twice their swelling in thickness.

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