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THE EFFECT OF SOME TECHNOLOGICAL FACTORS ON MECHANICAL PROPERTIES OF MDFs MADE OF WOOD OF HARD HARDWOOD TREE SPECIES

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ABSTRACT

On the basis of performed literature overview and analysis of the effect of production modes on mechanical indices of fibreboards, the following variable factors were determined: pressing temperature, board thickness and binder content.

In this paper the results of the performed analytical and empirical investigations with respect to the effect of pressing temperature, board thickness and binder content on mechanical properties of MDF-type boards (medium-density fibreboards manufactured after the dry method) made of hard hardwood species are presented. Regression models showing the effect of varied factors on board indices were derived. The changes in the values of those indices in case of combinations of levels of production factors were examined. Analysis of the result was made, with the respective conclusions being drawn.

Key words: MDF, mechanical indices, hard hardwood raw material, technological factors

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1. INTRODUCTION

Fibreboards are produced by means of drying or hot pressing of wood-fibre mass previously formed in a mat. Under wood-fibre mass, the product obtained after wood defibration is understood.

The method of production of fibreboards after the dry method was developed for the first time in the USA by Meyer in 1952. The first factory for MDF production was built in Deposit, USA, in 1965, and the first factory in Europe is considered to have been built in the former German Democratic Republic in Ribnitz-Damgarten in 1973 (Wiliams, 1995).

After laying its beginning, the production of MDFs showed considerable growth on a worldwide scale. At the beginning of the 1990s, it was declared to be "one of the most interesting new products for the last 50 years" (Anon, 1995). There was a huge optimism in the MDF industry at the beginning of the 1990s, which was intensified by the quick growth of both the production and the consumption. The consumption on the Old Continent increased in the 1990s by 500%. The consumption of MDFs per capita of the population in Europe was considerably higher in comparison to other continents. The production and consumption of MDFs in Europe increased drastically due to the huge production capacities. In 1999 only, the increase was by 2250 mn m^3. The production capacity increased most considerably in Austria, France, Spain, Germany and England, with it having increased by a total of 50%.

The MDF-type boards are a composite material consisting of lignocellulosic fibres combined with synthetic resins and pressed together under high pressure and temperature. The most often used lignocellulosic fibres are the wood-based ones, but other plant fibres may be used, too.

Fibreboards may be manufactured after the dry method with thicknesses of 2 to 72 mm and a very wide size range. The board density varies from 600 to 900 kg/m^3.

This type of boards is characterised by very good operating results, with them considerably excelling those of PBs. Because of their dimensional stability, MDFs find application both as structural and shaped elements in furniture production. In this type of board application, of major importance are their mechanical properties.

As a main shortcoming should be noted the high cost price of MDFs, which, on its part, necessitates that their production is realised with application of optimum, in view of the designed (set) properties, technological modes.

BACKGROUND

Hot pressing in the production of FBs is the process of highest importance for obtaining production with definite properties. The factors of the hot pressing mode are the most essential ones. The indices of the manufactured boards depend on them to the highest extent (Donchev, G.).

Investigations on hardboards produced on the basis of alkaline processes only, show that the thermal treatment leads to an increase of the bending strength. The increase of the pressing temperature (up to 175°C) of the boards with phenol-formaldehyde resin improves their strength indices (Donchev, G.).

The wooden mass and the thermal treatment have essential effect on the bending and ungluing strength. The addition of phenol-formaldehyde resin and the moisture content of wood fibres are of great significance for the retention of screws.

Garcia et al. (2006) noted that the thermal treatment of the fibres before pressing may considerably increase the dimensional stability of MDFs. During pressing with high temperatures, lower losses of strength were established when the pressing process was performed in nitrogen environment, in comparison to the steam one that, on its part, imparts better results in comparison to air environment. When the boards manufactured with isocyanate binder are exposed to rotting, the boards made of thermally treated fibres show improved resistance and the moisture content remains below 16% necessary for growth of mould (Burmester 1974). Goroyias and Hale (2002) established that several different variants of thermal treatment of composite materials may considerably increase the dimensional stability, but the resistance to rotting is increased to a much less extent. Deng et al (2006) found out that temperature, pressure, resin content, as well as moisture content affect the indices of MDFs.

The researchers Winandy and Krzysik investigated the effect of temperature and duration of pressing on physicomechanical indices of MDFs. The experiment was performed with fibreboards with density of 720 kg/m^3 and prognosticated thickness of 12,5 mm. Two control factors were used:

1) Pressing temperature –180, 200 and 220°C.
2) Pressing duration – 180, 270, 360, 450 and 540 s.

The experimental boards were made of wood of several tree species – aspen 60%, oak 15%, sycamore 15% and pine 10%. After defibration, the fibres were dried until reaching water content within 3-4%. Phenol-formaldehyde resin in the amount of 5% of the wooden mass was used as a binder. Additional refining additives were not used. The pressing process was performed on a hydraulic press at maximum pressure of 3,5-4 MPa, depending on the temperature. After performance of experimental investigations, they arrived at a conclusion that the mechanical indices of the fibreboards are cumulatively dependent on the duration and temperature of pressing. Optimum results were obtained at a pressing temperature of 200°C at duration of 450 s. The higher pressing temperature and the higher duration lead to destructive consequences to wood structure and to lower results.

From the above presented it should be concluded that thermal treatment (during pressing) is of essential importance for the indices of MDFs. Thermal treatment should be performed in modes in conformity with the type and amount of binder, as well as of wood raw material. It should be underlined that the structural and dimensional characteristics of the boards, mainly their thickness, are also significant factors when deriving optimum technological modes with respect to production.

Forests in Bulgaria are part of European and world forest wealth. In the last years, the total area of the forest stock has been continuously increasing, with it amounting at the end of 2010 to about 37%

of the total territory of the country, with 3738 mn hectares being covered with forests. The total wood supply of the country, calculated in 2010, amounts to 644 mn m^3. The annual increase amounts to 14,5 mn m^3, which makes 3,87 m^3 per 1 ha. Hardwood forests take about 68% of the forest area. Therefore, predominant in Bulgaria is the wood from hard hardwood tree species, with this also applying to increasingly higher degree of small-sized wood and wood of lower quality class.

The above presented is a prerequisite for updating with respect to investigation of the combined effect of temperature during hot pressing, binder content and board thickness on mechanical indices of medium-density FBs made of hard hardwood tree species.

2. MATERIALS AND INVESTIGATION METHODS

For the purposes of this investigation, wood fibre mass manufactured in Lesoplast, Troyan, after the Asplund thermo-mechanical method, with use of defibratorunits, was used. The processed wood raw material was a mixture of wood of common beech and cerris oak, with prevailing participation, approximately twice as much, of beech wood.

To determine the effect of the factors temperature, thickness and binder content, an optimum composition plan of B_3 type was applied. The experiment matrix is presented in Table 1.

The boards were manufactured during three-stage mode of hot pressing with total duration of 1 min/mm board thickness. During the first stage, the wood mat was pressed until reaching the desired board thickness, which was predetermined. The temperature conditions at this stage followed the data given in the matrix at a pressure of 2,5 MPa and duration of 1 minute.

During the second stage, polycondensation of the binders was carried out. During this stage, a steam and gas mixture of the binder and the mat was released. To this purpose, the pressure was reduced to 1,3 MPa. At this stage, formation of bonds between the elements building the boards takes place.

During the third stage, the pressure was reduced to 0,7 MPa. The stage is necessary in order that separation of the residual moisture in the board and formation of an additional amount of hydrogen bonds and van der Waals forces take place. The duration of the second and third stage is obtained by subtracting the time necessary for the first stage from the total duration and dividing it by two – for the second and third stage.

***Table 1**. Experiment matrix*

Temperature T, °C	**Board thickness, t_{bo}, m**	**Resin content, $p_{bind.}$, %**	**Temperature X_1, coded value**	**Board thickness X_2, coded value**	**Resin content X_3, coded value**
160	0,008	8	-1	-1	-1
160	0,008	16	-1	-1	+1
160	0,016	8	-1	+1	-1
160	0,016	16	-1	+1	+1
200	0,008	8	+1	-1	-1
200	0,008	16	+1	-1	+1
200	0,016	8	+1	+1	-1
200	0,016	16	+1	+1	+1
160	0,012	12	-1	0	0
200	0,012	12	+1	0	0
180	0,008	12	0	-1	0
180	0,016	12	0	+1	0
180	0,012	8	0	0	-1
180	0,012	16	0	0	+1
180	0,012	12	0	0	0

The main mechanical properties of MDFs were determined in conformity with the valid uniform European norms in the field. Variational and statistical processing of the results was performed, with regression models being derived by means of standard methods with application of *D*-optimum composition plans (Trichkov, N.).

3. RESULTS AND ANALYSIS

The results for the mechanical indices of FBs during the individual experiments from the items in the experiment plan are presented in Table 2.

The regression model for the effect of the factors on the bending strength is presented below:

$$\hat{Y}=32{,}63+1{,}68X_1-0{,}05X_2+4{,}56X_3+0{,}65X_1X_2-0{,}59X_2X_3+0{,}11X_1X_3-1{,}34X_1^2+0{,}25X_2^2-1{,}70X_3^2 \quad (1)$$

The model is characterised by a multiple correlation coefficient $R=\sqrt{1-\frac{Q_{resid.}}{Q}}=0{,}98$, with it adequately describing the subject investigated:

$$F=\frac{R^2(N-k)}{(1-R^2)(k-1)}=23{,}16 > F_{cr}\ (\alpha=0{,}05;\ \nu_1=9;\ \nu_2=5) = 4{,}77$$

Table 2. *Mechanical indices of FBs, at different levels of variation of factors*

No.	Board tempera-ture X_1	Board thickness X_2	Resin content X_3	Bending strength f_m, N/mm^2	Internal bond strength *ft*, N/mm^2
1	-1	-1	-1	24,27	0,14
2	-1	-1	1	33,51	0,28
3	-1	1	-1	23,60	0,14
4	-1	1	1	32,30	0,18
5	1	-1	-1	24,71	0,15
6	1	-1	1	36,19	0,35
7	1	1	-1	28,43	0,20
8	1	1	1	35,77	0,34
9	-1	0	0	28,57	0,23
10	1	0	0	33,94	0,31
11	0	-1	0	33,80	0,28
12	0	1	0	31,88	0,25
13	0	0	-1	26,46	0,18
14	0	0	1	35,32	0,33
15	0	0	0	32,78	0,25

The variation of the bending strength of the laboratorially manufactured boards depending on the set technological factors was established to be within 23 to 36 N/mm^2. Best bending strength index of 36,19 N/mm^2 was recorded in a board with 8 mm thickness, resin content of 16% and pressing temperature of 200°C, and lowest strength of 23,60 N/mm^2 was recorded in a board with 16 mm thickness, resin content of 8% and pressing temperature of 160°C.

From the regression analysis made, it becomes clear that the factor with strongest effect on the bending strength is the resin content. With the increase of the binder amount, considerable increase of the bending strength is observed. Second, in terms of significance, a factor in the variation ranges investigated, with nearly 3 times weaker effect, is the temperature during hot pressing. The board thickness factor has lowest effect at the variation range investigated, Figure 1.

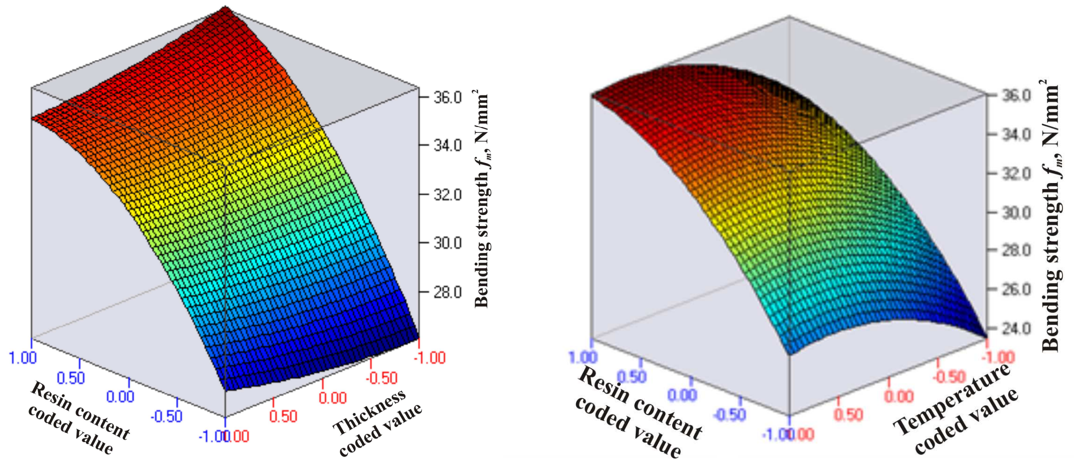

Figure 1. *Combined effect of the factors resin content and thickness, as well as binder content and temperature, on the bending strength of MDFs*

At the pressing temperature, considerable increase of the bending strength of MDFs to a factor value of 180°C was observed. This was followed by a stagnation of the values of the investigated index with subsequent decrease. The explanation of the latter may be sought in the partial destruction of adhesion bonds, at the set pressing duration. This phenomenon is compensable with variation of the levels of the remaining two factors investigated.

Out of the interactions, the strongest effect has the interaction between pressing temperature and board thickness, i.e. with the increase of the thickness, the temperature should be increased in order to achieve the same values of the index. The dependence is represented graphically in Figure 2.

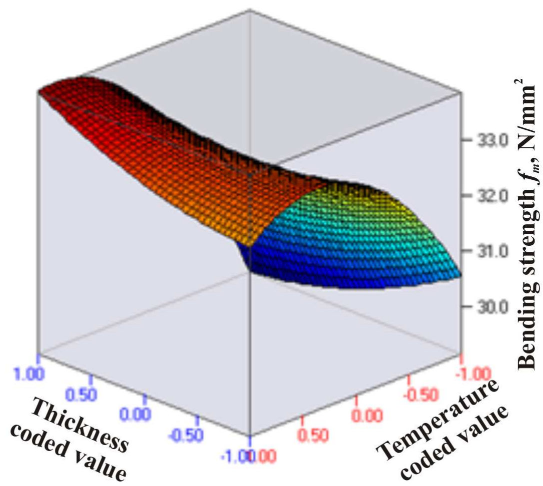

Figure 2. *Combined effect of the factors thickness and temperature on the bending strength of MDFs*

The regression model for the effect of the factors on the internal bond strength is in the form:

$$\hat{Y}=0{,}27+0{,}04X_1-0{,}01X_2+0{,}07X_3+0{,}02X_1X_2-0{,}02X_2X_3+0{,}02X_1X_3-0{,}01X_1^2-0{,}02X_2^2-0{,}03X_3^2 \quad (2)$$

The model is characterised by a multiple correlation coefficient $R=\sqrt{1-\frac{Q_{resid.}}{Q}}=0{,}99$, in case of check with F-criterion being established that it adequately describes the process investigated:

$$F=\frac{R^2(N-k)}{(1-R^2)(k-1)}=32{,}47>F_{cr}\,(\alpha=0{,}05;\ \nu_1=9;\ \nu_2=5)=4{,}77$$

At the set variation of technological factors, the change in the internal bond strength of the laboratorially manufactured fibreboards within the range of 0,14 to 0,35 N/mm² was recorded. Best transverse bending strength index of 0,35 N/mm^2 was recorded in a board with 8 mm thickness, binder content of 16% and pressing temperature of 200°C, and lowest strength of 0,14 N/mm^2 was recorded in a board with 16 mm thickness, binder content of 8% and pressing temperature of 160°C. From the regression analysis made, it becomes clear that the factor with strongest effect on the internal bond strength is the binder content. With the increase of the binder amount, increase of the bending strength is observed. The remaining two factors, pressing temperature and board thickness, have weaker effect. Second, in terms of significance, the factor with nearly twice as low effect is the temperature during hot pressing, at the factor variation range investigated. Here, the dependence is quadratic, with the internal bond strength increasing with the increase of temperature of up to about 185°C, whereupon a slight decrease of the index investigated is observed. The latter has a considerably low gradient in comparison to that in the bending strength. There is no clearly expressed advantage in the effect of the interaction of the factors on the index investigated, because their coefficients in the regression equation are similar. The effect of pressing temperature and board thickness on the internal bond strength is shown in Figure 3, with the highest values for the index investigated being shown in red, and the lowest ones – in blue. It is clear from the chart that the strength increases with the increase of the temperature. The dependence of the internal bond strength on the board thickness is more weakly expressed.

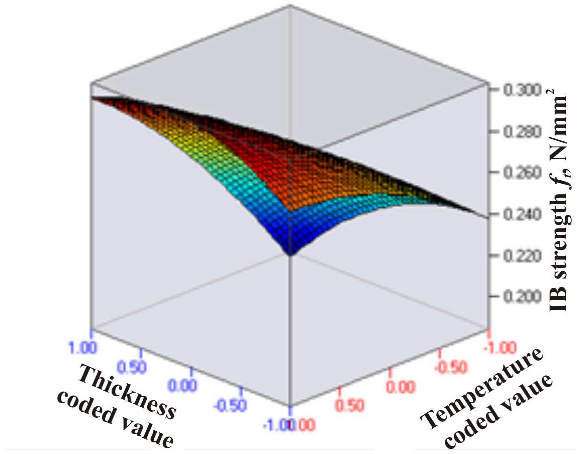

Figure 3. *Effect of pressing temperature and board thickness on internal bond strength of laboratorially manufactured FBs*

Figure 4 shows the effect of resin content and pressing temperature on the internal bond strength, as well as the combined effect of resin content and board thickness. It is clear that with the increase of the binder amount in the boards manufactured the index investigated increases within high limits. The increase of the pressing temperature also leads to better strength indices, though with lower degree of effect.

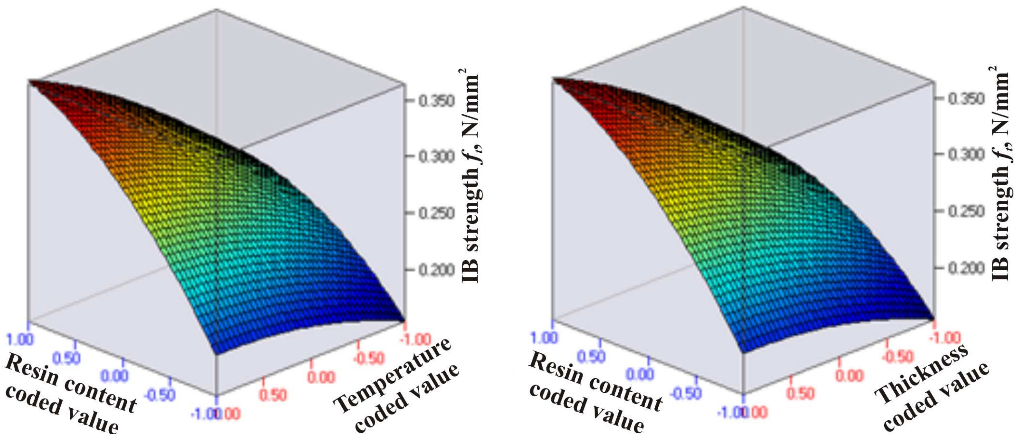

Figure 4. *Effect of pressing temperature and binder content, as well as binder content and thickness on internal bond strength of laboratorially manufactured FBs*

The above figure gives a clear idea of the positive effect of the resin content in the index investigated. With increase in the glue in the range investigated, the strength increases considerably. The board thickness has considerably lower effect on the values of this mechanical index.

4. CONCLUSIONS AND RECOMMENDATIONS

As a result of the investigation performed, the following more important conclusions may be drawn:

1) With increase of the pressing temperature and the resin content, the bending strength is considerably improved, with the effect of the binder being higher;
2) The internal bond strength is influenced to a highest extent by the binder content. A second additional factor with positive but lower effect is the pressing temperature;
3) All laboratorially manufactured FBs conform to the specifications for general purpose boards in dry environment and almost all meet the standard for general purpose boards in wet environment;
4) When designing the properties of medium-density fibreboards, the differently directed effect of temperature and binder content, on the one hand, and the board thickness, on the other hand, should be taken into consideration;

As recommendations to further investigations in this respect it may be shown:

– With a view to achievement of operating indices at lower values of the factors investigated, the density of the boards manufactured should be increased;
– In subsequent papers, it would be better to investigate the effect of the factors examined on the operating indices of fibreboards based on urea-formaldehyde resin, also investigating the pressing duration;
– With a view to achievement of optimum properties of the boards at possibly minimum binder content and/or pressing temperature, an optimisation of the subject investigated should be performed.

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