Some Correlated Factors Including Chip Surface of Bending Strength

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Abstract: - This scientific article presents some aspects referring to static bending strength and its influencing factors. It is an exhaustive study of all influencing factors but it only details the more important and known of these. Only three wooden species are used, namely beech (*Fagus silvatica L*), spruce-fir (*Picea abies Karst*) and poplar (*Populus tremula L*), for obtaining chipboard. Main factors which are considered that they influence the bending strength are: wooden specie, chip thickness, specific surface of chips, percentage of resin, specifical consumption of adhesive and board density. All of these are individually presented for finding the influence. Then, some of these are extracted and try to find all the influences between them. Finally, based on many rigorous experiments, a diagram for the grouped influence of some correlated factors, were realized. The main influence of bending strength that is found in this paper is chip thickness, but there are other hard points such as specifically surface of chips or degree of compressin-compactation

Key-Words: - chipboard, bending strength, factors of influence, correlated factors, chip thickness, resin percentage, specifical surface

1 Introduction

Bending strength is the most important chipboard resistance factor (along with cohesion bond), quantifying the combination between compression and tensile strength. Many researchers have approached this problem [2], but everyone from different viewpoints. For instance Klauditz [6] showed for the first time that, the bending strength depends on chip dimension, but the ulterior studies and researches in this field, are rarely taking this value as the single one. Generally, the influence from individual factors point of view was analyzed, but in the practice all factors are important and only correlated factors provide us with a more realistic perspective on their influence. In the domain of correlated-factors influence, the researches are huge even the domain are not the same. For instance Bica et al [1] find a lot of complex and connected factors of building materials which have a great influence upon health for the inhabitants. In the same way researchers Donke [5] and Diko [3] grouped some from all factors as “selected” or “system framework” ones. In the field of chipboard the influence of correlated factors upon bending strength are skimpy [4,], and do not take into account the chip surface, a very important factor for waferboard, flakeboard, OSB and other boards with great chip surfaces.

Generally speaking, static bending strength is defined as the resistance of the panel poses as a result to the force that tends to deform it, when the wooden sample is double supported on supports. The distance between bending supports is calculated as being 20 times the sample thickness. The device’s diameter for force applying and for support is at 30 mm, and the force velocity of applying is fixed as the time of testing to be 1±0.5 min, this usually represents a velocity of 10 mm/min [7]. General relation for bending strength calculus is similar to that of solid wood or other wooden materials (fibreboard, plywood, cardboard) with rectangle section:

$$\sigma_i = \frac{3}{2} \cdot \frac{P_{\max} \cdot l}{b \cdot g^2} \quad [MPa] \tag{1}$$

Where we have: P_{max} is maximum force of rupture for bending strength, expressed in N; l-distance between suports, expressed in mm; b-width of wooden samples, in mm; g-thickness of wooden samples, in mm.

Actualy, the above relation was determined from general relation of static bending, as a ratio between the bending moment (M_i) and the resistance modulus for cross section (W_z), namely:

$$\sigma_i = \frac{M_i}{W_z} \tag{2}$$

The bending modulus M_i can be determined related to force (P/2) and the arm of this force (l/2) as we see in figure 1:

$$M_i = \frac{P_{\max} \cdot l}{4} \tag{3}$$

The tranverse modulus of resistance is determined related to the form of cross section and could be for rectangle section:

$$W_z = \frac{b \cdot g^2}{6} \quad (4)$$

where: b- width of wooden samples, expressed in mm;
g- thickness of of wooden simple, expressed in mm.

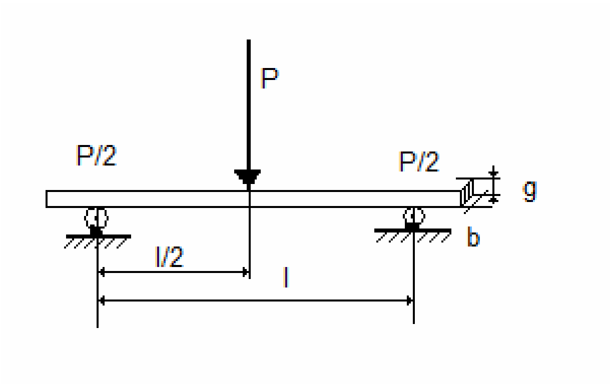

Fig 1. Scketch of static bending strength: P-force; l-distance between supports; b-width of wooden sample; g-thickness of wooden sample

Making the ratio between M_i and W_z, it will obtain the final relation of bending strength, as follows:

$$\sigma_i = \frac{M_i}{W_z} = \frac{\frac{P_{max} \cdot l}{4}}{\frac{b \cdot g^2}{6}} = \frac{P_{max} \cdot l}{4} \cdot \frac{6}{b \cdot g^2} = \frac{3}{2} \cdot \frac{P_{max} \cdot l}{b \cdot g^2}$$

2 Materials and working methodology

In conformity with the present standards EN 310, from each panel minimum 6 samples must be cut, in a rectangular form, with the following dimensions [8]:
-The length is 20 times the thickness, plus 25mm supplementary for each margin outside the supports, but not less from 150mm and no more than 1050mm;
-The width is 50mm;
-The thickness is equal with basis board thickness.

The bending strength for the entire board represents an average from all samples cut from each board (6 pieces from the point of view of European standard but usually 10 samples), arithmetic medium expressed with an accuracy of 1 MPa.

For laboratory experiments were used poplar, beech and spruce chips from practice for classical boards, chips which were cut on a machine with cylinder port-cutters (see Figure 2). Wide chips have been used from waferboard or flakeboard technologies (usual sizes 25×10×0.35mm), and also classical ones (usual sizes 20×4×0.35 mm), obtained after chipping by a cutter cylinder chipping machine from the following species of wood: spruce wood (*Picea Abies Karrsten.*), poplar wood (*Populus Tremula L.*) and beech wood (*Fagus Sylvatica L.*). The difference between the two types of chips is given by the widthof each category, the second category of chips being obtained by grinding operation, process that can affect only the chips width and finally their surfaces. First of all, the density of the participant species (beech, spruce-fir and poplar) of wood have been determined by cutting 10 prism shape samples of each material with the dimensions 20×20×30 mm [6], using the same raw materials as for the chips. The samples have been dried in a laboratory oven until a constant moisture content have been obtained, they were conditioned in the conditioning room until obtaining the moisture content of 10 % (because the moisture content of chips was the same), and the following average of the densities have been obtained after weighting the wood samples: beech wood 630kg/m^3, poplar wood 440kg/m^3 and spruce wood 410kg/m^3, values comprised in the range of the determined densities, found in the specific literature to this field [7]. Therefore, the moisture content of the chips used in the experimental work was of 10 ±0.5% and it was preserved by keeping the chips in well tight plastic bags, each plastic bag containing 100g chips of the same size type (grinded or not) and of the same wood type, related to wooden species. The amount of chips from the plastic bags has been successively halved (for the easiness of measurements) until obtaining the 32-th part of them [8] 500-1500 grinded chips to be measured, respectively 150-600 no-grinded chip, from each categories. This successively dividing method make the measurement of a smaller amount of chips to be possible, that amount is being representative for the whole quantity of tested chips. The measurement of the plane sizes was done by a digital slide gauge having an accuracy of 0.01 mm and the thickness have been measured by a dial gauge indicator, having the same measurement accuracy as the digital slide gauge. After measuring the chips sizes, their total area has been calculated, it has been multiplied by 32, obtaining thus the total surface for 100g of chips.

Chips were not broken up, but were dried in a laboratory box-dryer, to 90 Celsius degree, up to 5% moisture content and were kept in polyethylene sacks (up to the time of use). After that, the chips were mixed with 8-10-12% UF adhesive (dried resin) in a solution with 50% concentration, inside a mixing installation. Next, the formation mat is put in prismatic boxes with thin aluminum plates on the upper-side and lower-side for compacting and transportation and were kept in this stare a very short time up to the press-machine could be fed in good conditions. Then chip mats are pressed in the laboratory machine with hydraulic lifting at 2 MPa and electrical heat at 120^{0}C.

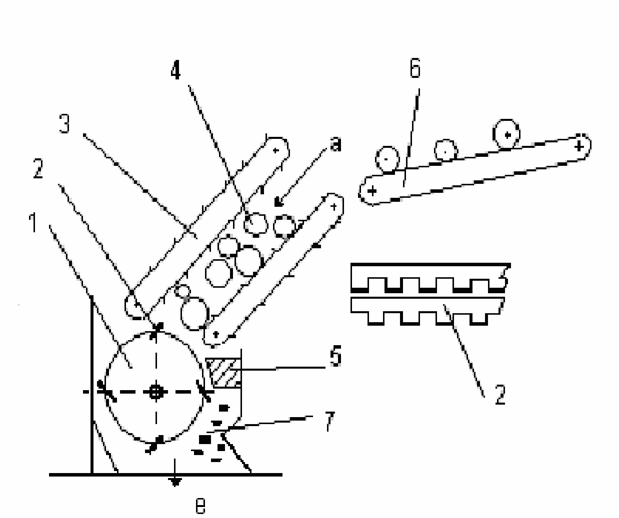

Fig 2. Machine with cylinder port-cutters for obtaining technological chips: 1- port-cutter cylinder; 2-special cutters; 3-feeding conveyer; 4-wooden material; 5-suport contre-cutter; 6 –feeding conveyer; 7-wooden chip

The principle of mat pressing is presented in Figure 3, where it can see the distancers 3, puted on the both two zone of plateaux, for obtaining a good equality of thickness on whole surface.

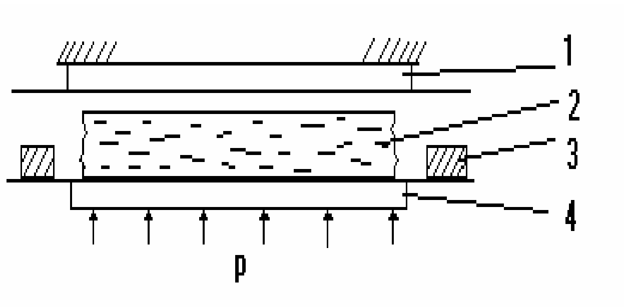

Fig 3. Sketch of pressing process: 1-superior plateau; 2-chip mat; 3-distancer; 4- inferior plateu; p- specifically pressure

From obtained boards, minimum 10 samples are cut and tested for bending strength on a universal machine for laboratory testing. All bending strength values were statistically worked. Overall, over 120 boards, with different percentage of adhesive, with different panel densities or of different chip categories (as dimension and quality), were realized, all of these for determining the influence of some factors on the bending strength of chipboards. The strategy of experiments put in evidence once again the diversity of influence factors and the corelation between them.

3 The main individual influencing factors of bending strength

The main chipboard bending-strength factors are grouped in two categories:

-Factors depending on raw material or technological material (resin, hardener, waxes), which are used in the technological flow;

-Factors depending on the manufacturing technology.

The main factors depending on raw material or used technological material are: wood species and their specific density, the chips compaction and compression, types of resin and their features (concentration, content of dried bodies etc), percentage of dried resin and so on.

On the other hand, the main factors depending from manufacturing technology are: chipboard density, features of chips, degree of compression and compaction, temperature of thermal agent, pressing technology with or without steam shock etc.

The chipboard density is the most important factor that influences bending strength. By increasing chipboard density, the bending strength (σ_i) will increase proportionally, as it is seen in all the literature articles [6, 7]. It could not forget the increasing of specifically consumption of raw material with increasing of chipboard density that has important impact on costs and price of chipboard. The influence is presented in Figure 4, for four different wooden species (beech, birch, spruce and poplar) but for the same conditions of manufacturing (dry resin 8%, length of chips 25 mm and so on). For instance, when the chipboard density is imposed at 700kg/m^3, the bending strength will be 22N/mm^2 in the case of beech or 40N/mm^2 in the case of poplar.

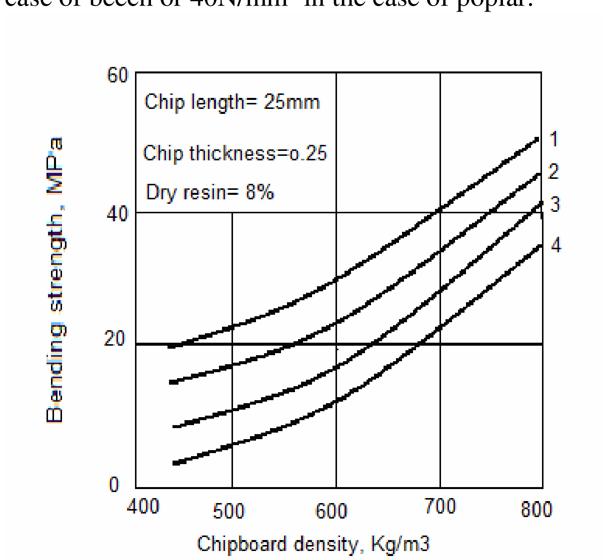

Fig 4. Variation of bending strength related to chipboard density and wooden species: 1-poplar; 2-spruce; 3-birch; 4-beech

The bending strength increasing is due to panel density increase and also depends on the wood specie used. Therefore, while pressing, the wood with small density is more compressible as bigger density wood. By compression and compaction and also by increasing the amount of wood substance in the volume unit, the wood's mechanical strength and thus the bending strength of chipboard will increase correspondingly.

The content of dried resin or **the percentage of dry resin contained by chipboard** has a favorable influence upon the bending strength, up to a certain point. The explanation for σ_i increasing correspondingly with the increase of adhesive dried substance is that of less intense penetration of adhesive inside the chip mass, and the remained adhesive on the chip's surface ensures a better participation of resin in the actually gluing process.

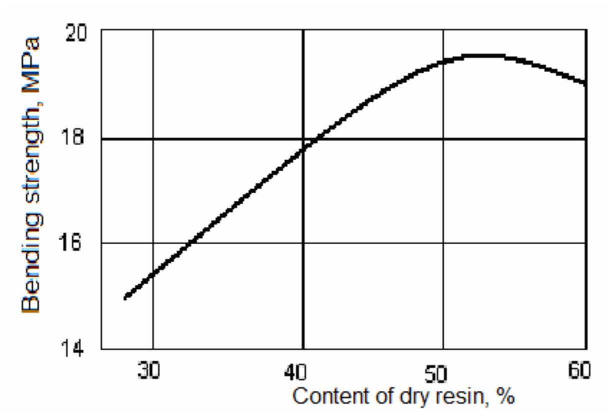

Fig 5. Influence of dry resin upon bending strength of chipboard

With increasing of dry resin content the chipboard density will increase proportionaly and the bending strength, too. This thing is shown by Figure 5, but up to a certain point about 52% of dry resin. Over this value of dry resin content the bending strength will decrease because it looses the elasticity of wooden chips and will increase the breakable dry resin.

Degree or coefficient of compactation-compression of wood from panel structure represents an other important factor of influence upon bending strength. When it is expresed as decimals is is called coefficient and when the exprimation is as per cent it is called the degree of compaction-compression. It is defined as a ratio between chipboard density and wood density (from what the wooden chips resulted).

$$k_{cc} = \frac{\rho_c}{\rho_w} \qquad (5)$$

$$\Delta_{cc} = \frac{\rho_c}{\rho_w} \cdot 100 \quad [\%] \qquad (6)$$

Where : k_{dd} is coefficient of compaction-compression; Δ_{cc} –degree of compaction-compression ; ρ_c- chipboard density, in g/cm^3 ; ρ_w- wood density, in g/cm^3.

For the sub-unit values it can consider that there is a compactation and for over-unit values of this coefficient there is a compression. The compression or compaction is refered to density of wood and chipboard, without taking into consideration the quantity or density of dry resin, which have some influences. This factor depends firstly by preasure as it could see in Figure 6. The Figure 6 is obtained experimentally making chipboards on a laboratory machine-press with different preasures. It had obtained an optimum values of preasure 1-1.5 MPa and a coefficient lower than 1.

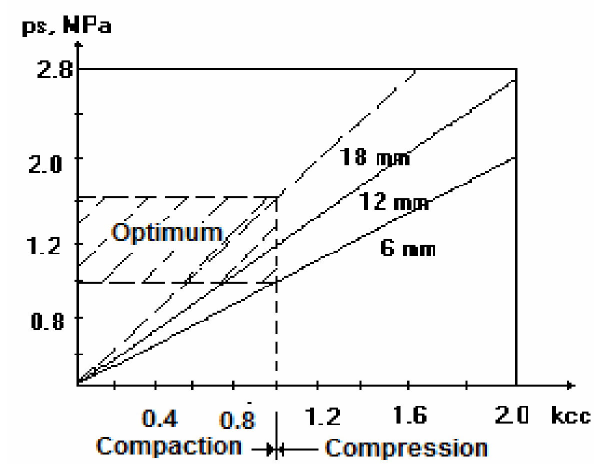

Fig 6. Coefficient of compaction-compression: p- preasure, in MPa; k_{cc}- coefficient of compaction-compression

By increasing of compaction-compression degree or coefficient, the wooden mass per volum unit of chipboard will increase, increassing in this way the bending strength. This degree of compaction-compression is superior limited by the designed chipboard density, because with increassing of compaction-compression degree the bending strength will increase proportionaly. General relationship between degree of compaction-compression and bending strength is the next [7] :

$$\sigma_i = \frac{\Delta}{\rho_0{}^x} \cdot k \quad [MPa] \qquad (7)$$

where : Δ is degree of compaction-compression for wood, ρ_0 – density of oven dry wood, in kg/m^3; x- coefficient dependent by chipboard density; k-coefficient dependent dby wood density.

Table 1. Relationships of chipboard density related to wood density [11]

Density,kg/m3	Coef x	Coef k	Relation σ_i
0,45	3,978	5,444	$\sigma_i = \frac{5{,}444 \cdot \Delta}{\rho_0^{3{,}978}}$
0,50	3,232	13,645	$\sigma_i = \frac{13{,}645 \cdot \Delta}{\rho_0^{3{,}232}}$
0,60	2,209	55,04	$\sigma_i = \frac{55{,}04 \cdot \Delta}{\rho_0^{2{,}209}}$
0,65	1,941	87,06	$\sigma_i = \frac{87{,}06 \cdot \Delta}{\rho_0^{1{,}941}}$
0,80	1,507	241,6	$\sigma_i = \frac{241{,}6 \cdot \Delta}{\rho_0^{1{,}507}}$

By replacing the value of two coefficient depending by chipboard density and wood density it will obtain many relationships, as it could see in Table 1.

It can be observed that the variation of bending strength related to the degree of compaction-compression is lineal. If the necessary calculation are made for the poplar specie (with an oven dry density of 440 kg/m^3) and the relationship for a chipboard density of 650 kg/m^3 (good for poplar) are used, the linearity of dependence will be obtained [3, 4].

Panel thickness is one of the less significant influencing factors for bending strength. The idea of this influence is also found in the analysis of Romanian standard STAS 6438-86, which stipulates the minimal resistances depending on panel thickness, as follows:
-for under 12 cm thickness, the admissible bending strength must be at least 20 MPa;
-for 12 to 19 mm thickness, the minimal value has to be 18 MPa;
-for over 19 mm panel-thickness, the value must be at least 16 MPa.

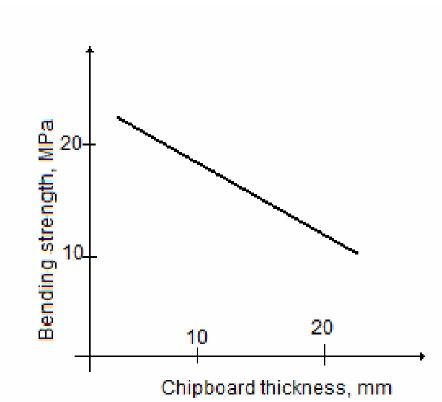

Fig 7. Direct influence of chipboard thickness upon bending strength

It is a fact, that by decreasing panel thickness, the bending strength migth increases, as the Figure 7 show us. Therefore, the chips for chipboard with more density are more plasticized and compacted, a higher bending strength being obtained. This influence can be practically computed from experimental results as it is shown in the diagram from Figure 8.

From the Figure 8, it can be seen that the bending strength omodulus of rupture depends firstly on panel density and secondly on wooden specie. For example, for a panel thickness of 10 mm and a panel density of 700 kg/m^3, we will obtain a resistance of 17 MPa for beech and 24 MPa for spruce-fir specie (*Picea abies*). Because we have two inter-current influencing factors (panel density and wood specie), the force of rupture was utilized as a linking element. Only in this way the influence of thickness was be realized.

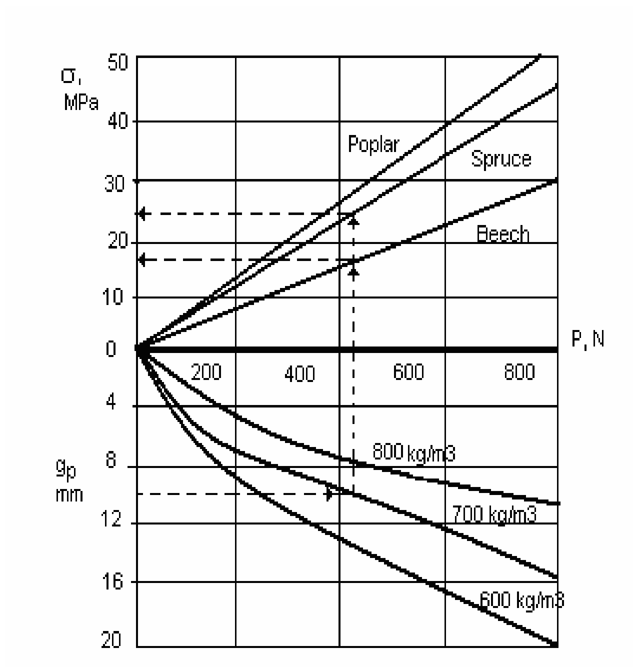

Fig.8. The influence of panel thickness upon modulus of rupture of bending strength: g_p – panel thickness, in mm; P- rupture force, in N; σ- modulus of rupture or bending strength

The specific adhesive consumption (defined as the ratio between dried resin mass and chip surface) has an positive influence upon bending strength, this influence also depending on panel density (see also Figure 9). General relation of this factor is the next one:

$$c_s = \frac{m}{s} \quad [g/m^2] \qquad [8]$$

where: m is mass of resin, in g; s-surface of chips, in m^2.

Based on experimental results, the diagram from Figure 9 was realized. This diagram was realized on the base of tendency points, for each point minimum 10 value were used.

The bending strength or modulus of rupture will increase correspondingly with the specific consumption increase as shown in Figure 9. For instance, when the specific consumption of adhesive is at level 10 g/m^2, the resistance for static bending will be at 14 MPa (for 600 kg/m^3 panel density) and 22 MPa (for 700 kg/m^3 panel density). All of these values are valid only for poplar chips with an average thickness of 0.38 mm. The correlation between specific consumption of adhesive and the percentage of adhesive used (both of them having a good utilisation for producers) is obtained by means of specific chips surface and will be presented bellow.

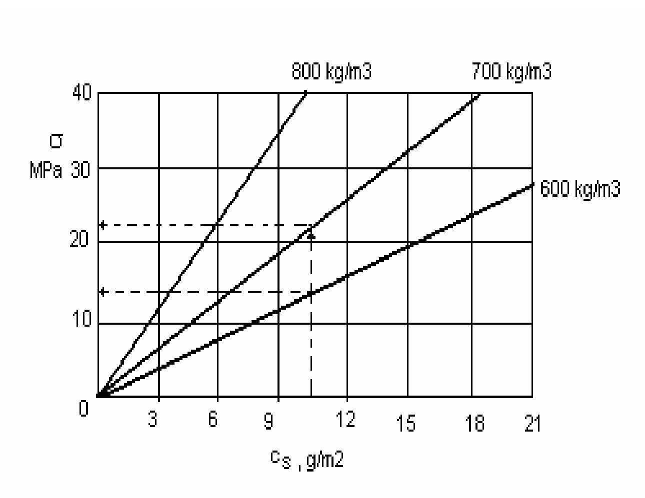

Fig 9. The influence of specific consumption of adhesive on bending strength for poplar chips

4 The correlated factors of bending strength influence

In the chipboard manufacturing process all bending-strength factors are not found individually, but together contribute to the increasing or decreasing of it. An old diagram with correlated factors of bending strength influence is presented in Figure 10, and was realized for the next features of manufacturing technology and chipboard:

- Chipboard with omogen structure;
- Chipboard thickness of 25mm;
- Chip thickness of 0.1-0.2mm;
- Percentage of dry resin of 8%;
- Percentage of other substances 1%;
- Moisture content of chipboard 8%.

This nomogram from Figure 10 could be used starting from two distinct points, namely the chipboard density and density of oven dry wood (that is introdused in chipboard). For instane, as it could see on diagram, if it has a chipboard density of 0.650g/cm^3, it draw a verticale line up to the corelation curve, from what it draw a radial line up to the origine point O(0;0). In this moment it can start from the second point of density for oven dry wood (for instance 0.5g/cm^3) up to reach the precedent radially line. It could draw an horizontal line an obtain in the left the cofficient of compaction-compression (with a value of 0.9, high), and in the rigth part the same horizontale line will cut again a new curve of chipboard density (the same of 0.650g/cm^3).

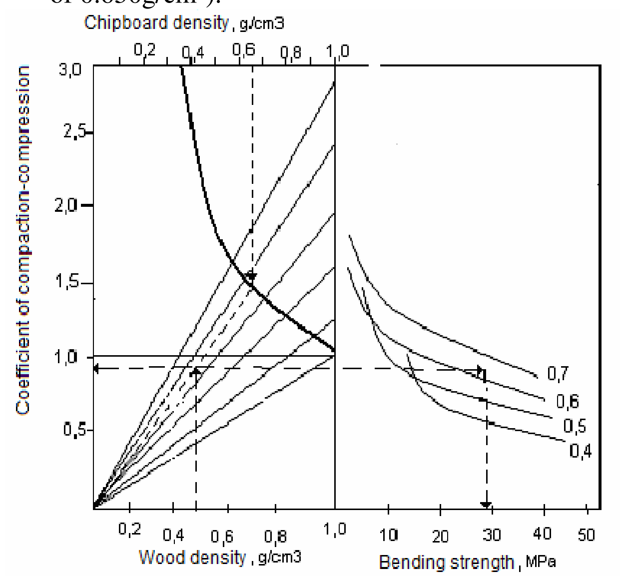

Fig 10. Diagram of corelation of bending strength with wood and chipboard and coefficient of compaction-compression [10]

The verticale line from this point down-step will offer us the bending strength, namely 29 MPa.

The main deficiences of this diagram can be sintetized as follows :

- do not keep into account the chip surfaces ;
- the chipboard density is twice used ;
- has two entrances, being hard to use.

Therefore a lots of experiments were done to find a new diagram over these deficiences. In this article a lot of theoretically and experimentally testing was realized, in order to find a diagram with three dials, for correlating the main factors of influence upon bending strength. One of these diagrams, particularized for the poplar specie, is presented in the Figure 11, where the main combined factors of influence (wooden specie, chip thickness, specifically surface of chips, percentage of adhesive, specifically consumption of adhesive and panel density) are shown.

This diagram is obtained piece by piece, based on both practical and theoretical experiments. From the practical point of view, over 120 types of experimental boards were realized having different density, adhesive consumption and so on.

The first part of the diagram (the upper right dial) was realized through theoretical and practical methods. In the first method, the theoretical one, we consider 100 grames of chips (see Figure 12) from a certain wood specie (beech, for instance with the wood density of 0.630 g/cm^3). For a chip thickness of 0.2 mm, the total chip surface will be calculated (1.587 m^2/100g), based on the volum of 100g of wood, and the number of chips. It is easy to see that the rectangle parallelepiped, taken as a model, has the upper-side surface of 10×10 cm. For a thickness of 0.4 mm the other specific surface will be obtained. Other specific surfaces can be obtained similarly for other thicknesses of 0.6mm.

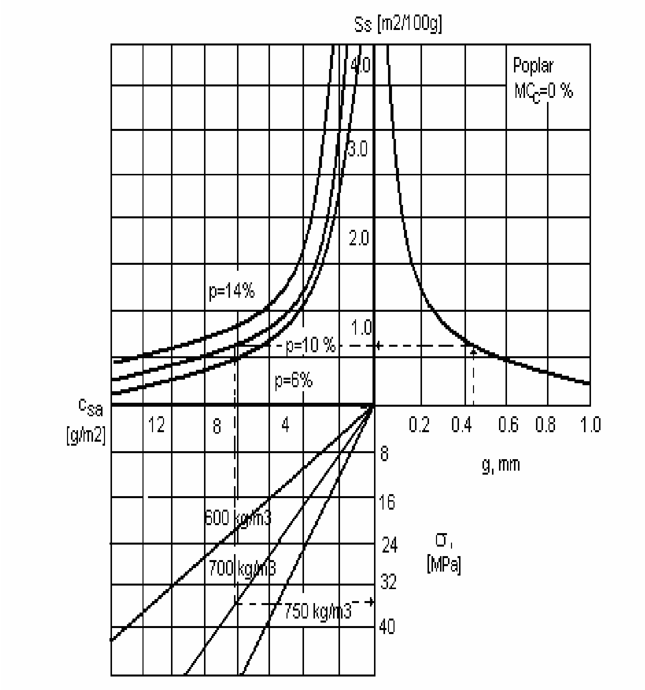

Fig 11. The diagram of the main correlated factors of bending strength (for beech specie): g is chip thickness; Ss-specifical surface of chips; c_{sa} – specifical consumption of adhesive, in g/m^2; σ- modulus of rupture for bending strength

This above methodology can be applied also for other species like beech *(Fagus silvatica L)* or spruce-fir (*Picea abies*).

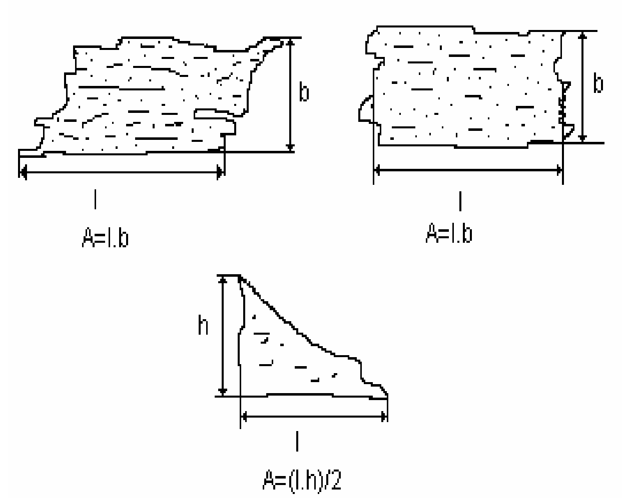

Fig 12. Chip shape types and the way of calculating their surfaces

The average value of the measured thicknesses of the chips has been also calculated and recorded. For each type of chips (three species of wood, two average value of the width), 10 measurements of the surfaces have been done, all of them being recorded in the tables, for determining the average values. Those values, very close to the ones found in the specific literature [9] were used to confirm the theoretical method presented below.

The chips specific surface can be theoretically determined using a virtual cutting model of a wooden compact block in several layers and by calculating their area. For the beginning, a solid wood block of 100 g is supposed to be cut in layers having various thicknesses in the range of 0.1, 0.2,…, 1.0mm (see Figure 13). First of all, the total number of obtained layers is calculated, than the area of one layer of wood and at the end, the total area of the wooden layers for the entire block of wood of 100g weight (see Figure 12). The calculation is made separately for the three species of wood which are experimented (beech, poplar and spruce) and for each thickness size, from 0.1mm till 1mm, with a step of 0.1mm.

In case of beech wood, for example, the following steps are to be followed in order to calculate the chips total surface:

- the density of the beech wood (*Populus tremula L*), previously determined, for a wood moisture content of 10% and an amount of 100g of chips is 0.630g/cm^3;
- based on the two values, the volume of the solid wood block is calculated now by considering that the sum of the chips mass equals the mass of the solid wood block (without waste): 158.73cm^3;

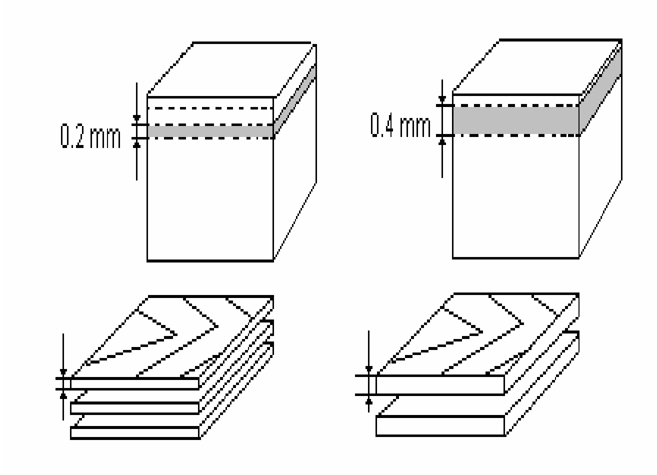

Fig.13. Theoretical model used to determine the specific surface of the chips

- based on the previously calculated volume and on the supposed sizes of the block base (10×10 cm) for a weight of 100g solid wood, the height of the block is calculated: 1.587 cm;
- considering the thickness of the cut layers of 0.2 mm, the total number of layers is calculated: 79.365;
- multiplying the number of layers with the layer area (2×10×10cm), the total area of the layers cut from the entire solid wood block is obtained, as shown bellow:

$$S_s = 2 \cdot S \cdot n \cdot 10^{-4} = 200 \cdot 79.365 \cdot 10^{-4}$$
$$= 1.587 m^2 / 100 g chips$$

- in a similar way, for a layer thickness of 0.4 mm, a total number of layers (n) of 39.682 is obtained and also the specific area of the chips of 0.793m^2/100 g

Table 2. The specific area of of surface for 100g chips, depending on the species of wood and of the thickness size of the chips

Thickness of the chip, mm	Specific area of the chips, in m^2 /100g chips		
	Spruce wood (ρ_{10}=410 kg/m^3)	Poplar wood (ρ_{10}=440 kg/m^3)	Beech wood (ρ_{10}=630 kg/m^3)
0.1	4.878	4.545	3.174
0.2	2.439	2.272	1.587
0.3	1.626	1.515	1.058
0.4	1.219	1.136	0.793
0.5	0.974	0.909	0.634
0.6	0.813	0.757	0,529
0.7	0.696	0.649	0.453
0.8	0.609	0.568	0.396
0.9	0.542	0.505	0.352
1.0	0.487	0.454	0.317

All the obtained data base for the poplar, beech and spruce wood, determined by this method, is shown in Table 2.

The values presented in Table 2 shows the tendency of decreasing the specific area of the chips with the increasing of the chip thickness size, but the variation rule is shown only by the diagram in Figure 14. Special computed program give us aditionaly no-linial equation (Figure 14), that caracterized law of variation in this case. The values from Table 2 and diagram from Figure 14 represent one of simple method for determining the specifical surface of chips. It can observe the easy determination of specifical surface for chips for all three wooden specie, even for other chip thicknesses, by linial interpolation. The main desadvantage is reffering to wooden specie, respectivelly in the case of other species the methodology must be replicated and other tables or diagrames must be realized.

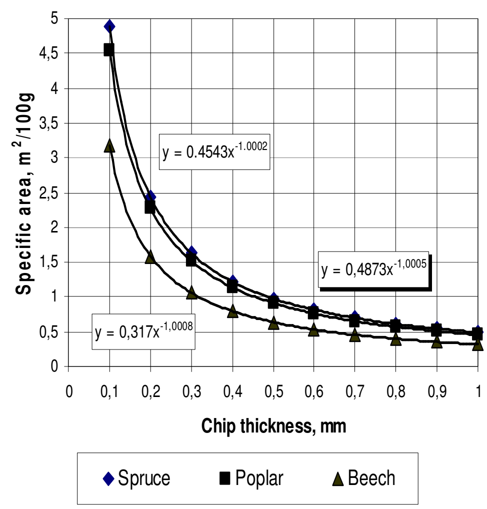

Fig. 14. The variation of the chip specific surface by the wooden species and chip thicknesses, for the three different wooden species

An other proposed method is based on the algorithm of the above method, in order to determine a fast way of calculating the chips specific area, namely o simple relationship. For this purpose, the start point will be the equation of determining the wood mass depending on its density and volume (wood mass = wood density × wood volume), namely:

$$M_w = V_w \cdot \rho_w$$

If the presumption of equality between the wood mass and the total sum of the chips mass is done (no waste and wood pores considered), then the equation is transformed as follows:

Chips mass = wood density × wood volume (see equation 1).

$M_{ch} = V_w \cdot \rho_w$ (9)

If the equivalence between the volume of the wood and the multiplication of the total chips area by their thicknesses is done, then the following equation can be used:

$M_{ch} = g \cdot S_s/2 \cdot \rho_w$ (10)

Where:

M_c is the chips mass;

S_s – specific area of the chips, in m^2/g;

ρ_w – density of the wood from where the chips were obtained, in kg/m^3.

In the previous equation (10), $S_s/2$ represents a half of the chips area S_s, necessary to calculate the volume of the solid wood block.

From the previous equation (10), S_s is extracted and the following general equation results:

$$S_s = \frac{2 \cdot m_{ch}}{\rho_w \cdot g} \quad [m^2/g \quad chips] \tag{11}$$

Coming back to equation 10 and replacing the mass of the chips with the value of 100g, the next particular equation is obtained:

$100\ g = g \cdot A/2 \cdot \rho_w$ (12)

The specific area of the chips becomes as follows:

$$S_s = \frac{200}{\rho_w \cdot g} \quad [m^2/100g \quad chips] \tag{13}$$

We have obtained two equations: equation (11), respectively for the general case and equation (13) for the case of 100g chips, easy to be used for a fast calculation. For example, if the specific area of the spruce chips of 0.4 mm thickness is to be known, using equation (13) we will obtain: S_s=1.136 m^2/100g chips. The obtained value corresponds to that obtained through the above method, shown in Table 2, confirming this theoretical method. More than that, the equations (11) and (13) can be used also when the thickness of the chip or density is different by the values indicated in the examples shown before. The condition of using the present theoretical method, easy to use is to know the density of the wood species from where the chips are obtained. For example, the calculated specific area (S_s) of the chips obtained from pine (*Pinus Strobus L*), with a density (ρ_w) of 480 kg/m^3, having a chip thickness of 0.32mm, is 1.302 m^2/100g chips. In the next rows it illustrates the step by step calculus for obtaining the poplar specific surface, as fallows:

-the oven dry density of poplar specie 0.630g/cm^3 and mass of oven dry wood 100g are known ;

-the volume of oven dry wood, corresponding to 100 g chips can be calculated, as the ratio between mass and density, namely 158,73cm^3;

-knowing the volume and the surface (10×10cm), the total thickness of a wood block corresponding to 100 g chips can obtained, namely 15.8mm;

-by dividing the total thickness to the layer thickness (0.2mm), the total number of layers from wood block can obtained, respectively 79.36 pieces;

-by multiplying the number of layers with the surface of a single layer (2×10×10cm), the total specific surface of chips 1.587 m^2/100g chips is obtained;

-following the same algorithm, the specific chip surface of 0.793 m^2/100 g can be obtained for a thickness of 0.4 mm, and the specific surface of 0.529 m^2/100 g, for a 0.6 mm thickness.

The second method for finding the correlation between chip thickness and specific surface, from the first diagram dial, is a practical one, because the real surface for 100g chips is determined through measurements.

The second dial of the diagram from Figure 11 represents the correlation between chip specific surface and the specific consumption of adhesive by means of the percentage of dried resin. The definition relations for each term are:

$$p = \frac{m_{0a}}{m_o} \cdot 100 \quad [\%] \tag{14}$$

$$c_{sa} = \frac{m_{0a}}{s_a} \quad [g/m^2] \tag{15}$$

$$s_a = s_s \cdot m_0 / 100 \tag{16}$$

Where: p is the adhesive percentage; m_{0a} – mass of dried resin; m_0 – mass of oven dry wood; c_{sa}-specific consumption of adhesive; s_a – chips active surface; s_s – specific surface of chips, related to 100 g chips.

Finally, from the three relations above results next relation:

$$c_{sa} = \frac{p}{s_s} \quad [g/m^2] \tag{17}$$

Based on the last relation (17), the second dial of diagram (the upper left dial) was realized, using a theoretical procedure, but with real values.

The third dial of diagram (the lower left position) from Figure 11 was realized by practical experiments, respectively realizing a lot of chipboards, with different panel density and different adhesive consumption. Putting these values in the graphic and determining the bending strength, the third zone of diagram can be obtained.

Conclusions

Bending strength along with internal cohesion are the most important mechanical properties of chipboards. The studies presented in this article, highlighted the variety of influencing factors, and also the individual influence of each. Aside from these, the main problem discussed in this article is that the individual influence of each factor is not as important as the correlated influence of these factors, and only that will offer us veridical data of great importance for chipboards manufacturers. In this article, both the theoretical and the practical methods were integrated, in order to achieve good resistances with low consumption of adhesive and wood at low density in chipboards.

The method, applied by using equation (13) is an easy way of calculation for a diversity of thicknesses and species, no matter of how many decimals they have as a value. As a final conclusion of the paper, the authors recommend the method expressed by equations (11) and (13) as the easiest way of calculation the specific area of the chips, no matter of the wood species or of the chip thickness. The obtained results have also shown that no differences between the surfaces of the grinded and no-grinded chips occurred, the first opinion that these kind of differences exist (because of the differences between the internal cohesion of the boards obtained by gluing them) being clarified only based on the other chip characteristic, namely the bond surface, which represents a part of the specific area of the chips [8]. This is the reason why the specific surface of the chips S_s is also known as a potential bond area.

The obtained diagram represents a correlation model for many influence factors and for obtaining good chipboard strength on the manufacturing flow. Regarding this aspect, the paper is helpful for chipboard producers, in finding an optimization related to all influencing factors.

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