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CONTRIBUTIONS TO THE CURVATURE RADIUS AND BENDING CAPACITY OF VENEERS

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ABSTRACT

The curvature radius is one of the veneer properties that is connected to wood elasticity and can be used in the molded furniture industry. This paper refers to the methodology of determining the minimal curvature radius and after wards, by relying of this methodology, the bending capacity of veneers. Furthermore, the devices that are used in determining the minimal curvature radius and the main influencing factors such as species, density, thickness, moisture content are also presented. A chart for determining the curvature radius related to veneer thickness is obtained and a linear equation is then found, on this basis. The final results and analysis emphasize the importance of these characteristics, when veneers are used in molded products.

KEYWORDS: Curvature radius, bending capacity, molded product, veneer.

INTRODUCTION

Veneers are superior engineered products, made from round wood; aesthetical veneer is obtained when cutting is done by plane cutting or eccentric rotary-cutting (using valuable species) and technical veneer when cutting is done by centric rotary cutting (Kollmann and Côte 1968; Mitisor 1977, Matuana et al. 1998, Rahman et al. 2012). There are numerous veneer properties and some are related to veneer elasticity such as, for instance, curvature radius (Longuleasa and Brendofern 1991). Some articles describe many mechanical properties of composite materials made of veneers. For instance an investigation (Pfriem and Buchelt 2011) aimed to compare the mechanical behaviour of lengthwise and plain sliced veneer of the beech species. As a main result it can be stated that lengthwise sliced veneers exhibit significantly more strength and mechanical characteristics than plain sliced veneers. Due to their higher strength values, lengthwise sliced veneers are considered better materials for engineered wood products than plain sliced veneers. Buchelt and Wagenführ (2010) obtained a composite made of a 0.35 mm thick from beech veneer and a 0.12 mm cellulose film bonded with a vinylic adhesive. The modulus of elasticity (MOE) of this composite perpendicular to the wood fibre is considerably increased, which is detrimental to the flexibility of the entire composite. On the other hand, another paper (Bekhta et al. 2012) explains the influence of initial veneer pressing on the final composite process. The initial veneer densification before the pressing of composites allows lowering both the glue spread from 150 to 90 g.m^{-2} (40 % reduction) and the pressing pressure from 1.8 to 1.0 MPa (45 % reduction). Densified wood showed a reduced saturated moisture content and equilibrium moisture content of veneers (Cloutier et al. 2008). It has been established (Sorn and Bajramovic 2009) that, there is a difference between flexural strength and ways of loading Laminated Veneer Lumber (LVL), namely the position of veneer during pressing, either edgewise or flatwise. The values of bending strength MOR and modulus of elasticity MOE for solid wood were smaller than those of laminated products LVL, made of the same veneer species (Nazerian et al. 2011). Results show that veneer arrangement and adhesion are the main causes of change in the mechanical and physical properties of boards made of veneers.

The curvature radius of wooden veneers is used in molding operations in order to obtain molded laminate composites. The molded laminates are increasingly used in furniture manufacturing of stay, ding, decorating, paneling, etc., as exemplified in Fig. 1 for chairs and armchairs.

Fig. 1: Chair and armchair made of molded veneers.

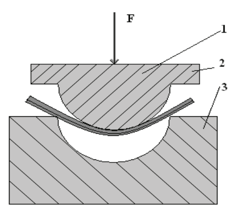

Fig. 2: Bending the veneer package in real process: 1 -upper mold; 2-veneer package; 3-lower mold.

When veneer packages are molded even right when the curving process begins, the danger of sheets breakage can appear mainly because of the absence of correlation between the real radius of the finished product and the minimal radius of the veneer curvature. To avoid this inconvenience it is necessary to know the minimal bending radius of veneers. This characteristic can be defined as a minimal radius of veneer obtained when the veneer is curved and broken. The minimal radius of curvature for molded products is the same as the minimal radius of individual veneers.

Choosing veneer thickness in order to form the package depends mainly on the minimal curvature radius of the glued block of veneers. By reducing the thickness of veneers, the package can easily curve without cracks on smaller radii, but the number of veneer needs and adhesive consumption increase. In the same case, when using aqueous solution of adhesives and thin veneers, the amount of water from the package also increases and this will reflect negatively on the stability of molded block. Removal of such defects, which occur frequently in the case of molded products with small curvature radii, is done by the introduction of film adhesives but with higher costs. Studies on the minimum curvature radius were made by other authors (Petrican et al. 1979), but they only managed to determine the curvature radius. Studies were also focused exclusively on veneer properties and not on the connection with the final molded product.

The main objective of this paper is to find the minimum curvature radius of veneers, in order to obtain molded products with good features. Additionally, finding the bending capacity and the influence factors of the curvature radius are other aims of the paper.

The curvature radius is usually determined using a device with several successive radii that curve veneers. Since the minimal radius of curvature depends mainly on veneer thickness, a new notion has been put forward namely the bending capacity which takes into account the thickness of veneer. Bending capacity is determined from the ratio of the curvature radius and the thickness of veneer (Eq. 1).

$$C_b = \frac{R_c}{t} \tag{1}$$

where: C_b - bending capacity,
R_c - curvature radius,
t - thickness.

As other authors stated (Petrican et al. 1979) that there is a simple veneer curvature when the process is stopped at bending or a complex one when during the bending process a compression force of the veneer package is applied, thus reducing initial thickness (Fig. 2).

Nevertheless, there could not be a molding process without pressure and compression. However, the two types of bending do not have a major influence on the minimal bending radius of veneers, but usually the complex bending easily reduces the value of the minimal curvature radius.

MATERIAL AND METHODS

For all experiments, it started from the assumption that the minimal radius of curvature and bending capacity for package blocks was approximately the same as for individual veneers. Therefore the experiments (without the last part) were made on individual veneers. Determinations were based on a specific method. From each of the samples (veneer sheet of beech, spruce and oak species) 10 specimens with the length parallel to the grain, 5 from the central area and another 5 from the margins of the veneer sheet, with 25 in width and 600 mm in length were cut. To determine the minimal radius of bending it used a device consisting of several superimposed circular or half-circle pieces with diameters of 25, 30, 35, 40, 50, 60, 80, 125, 150, 200, 250, 300, 350, 400, 450, 500, 600, 700 mm and a height of 30 mm each, as the circular device is shown (Fig. 3).

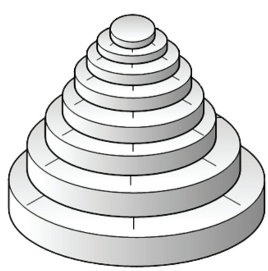

Fig. 3: Device for determining the minimal curvature radius.

In bending the veneer block with upper and lower mold, part of the devices used should be large enough to overcome the bending strength of the veneer package and also the friction that occurs between veneer sheets. The flexural strength of the veneer package is given by the sum of forces for each veneer and total friction, by the cumulated friction of all veneers. Friction does not depend on veneer surface but only on the friction coefficient, mass and forces. For this reason the friction between veneers is small and can therefore be neglected. Consequently, pressing forces are not a problem in obtaining mold furniture and other wooden objects but only the curvature radius of molded products.

Experiments related to the curvature radius were performed on three European species (beech- *Fagus sylvatica* L, oak- *Quercus robur* L. and spruce- *Picea abies* Karst). Specimens were bent by hand twice on a circular (or semicircular), first with the veneer face outward and second with the backside outwards (in order to eliminate the influence of the veneer face and backside). All testing started with bending each specimen of veneers on the semicylindrical with a diameter equal to 100 times the specimen's thickness. The minimum radius of curvature was considered the superior size that occurred by bending some breaks (not necessarily resulting in total destruction) such as cracks or fissures.

The next stage in the research was determining the influencing factors and the manner in which they could influence the process of molding products from veneers. The main influencing factors that have been analyzed in the paper were: wooden species, thickness and moisture content of veneers. Four beech veneer thicknesses and others five moisture content values were analyzed, respectively 0.7, 1.0, 1.5 and 1.8 mm thick and 0, 4, 8, 12 and 16 % moisture content.

The last part of experiments was directed at achieving a chair belt from beech veneer, given the choice of veneer according to minimum curvature radius and/or bending capacity. This part of the research took into account the radius of curvature of the chair belt, or the choice of veneer thickness used for this product.

RESULTS AND DISCUSSION

Firstly some results were applied on the curvature radius of oven-dried veneer and with five moisture contents (according to the methodology). During the experiments numerous tables were devised for each species, as shown in Tab. 1 for the beech species. The summarizing of the data for all analyzed species are shown in Tab. 2.

Tab. 1: Determination of the curvature radius and bending capacity.

Species and features	Minimal curvature radius (mm)	Mean radius mm	Bending capacity
Beech (*Fagus sylvatica* L.) Moisture content: 8 % Density: 700 kg.m^{-3} Thickness: 0.7 mm	30	28	35
	30		
	30		
	30		
	30		
	30		
	25		
	25		
	25		
	25		

Tab. 2: Curvature radius of and bending capacity of veneers.

Wood species		Density (8 % MC) ($kg.m^3$)	Curvature radius (mm)	Bending capacity
Beech	Thickness 0.7 mm	700	28	35
Oak		670	36.8	46.0
Spruce		450	38.0	47.5

Using bending capacity values (Tab. 2) all wooden species can be classified from the point of view of veneer use for molded products (beech, oak and spruce, in ascending order). It was noted that this feature depends mainly on the density of the wood species, but not exclusively, because there is no perfect proportion between them.

Veneers obtained by rotary or plane cutting have two surfaces, namely the face defined as the part that comes into contact with the seating face of the knife and the backside or the face that comes in contact with the reverse face of the knife (Fig. 4), largely affected by cracks (when the cutting process is not conducted properly). When the preliminary experiments were performed, the influence of the face or backside of veneers upon the minimal curvature radius and bending capacity resulting during the experiments (10 trials each, for the front and for the backside of veneers) were not significant (in the range of ± 3 %), although some authors state that there are significant differences of about 30 % (Petrican et al. 1979). In fact, these differences are given by the knives' sharpness and compliance with cutting parameters and not by each well-cut veneer. Therefore it is not important to study the minimum bending radius according to the face and backside of veneers. Moreover, in order to eliminate this drawback, the working method demanded the bending of veneers on their face and backside.

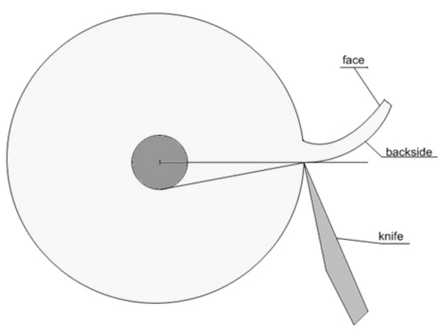

Fig. 4: Face and backside of structural veneer obtained by rotary cutting.

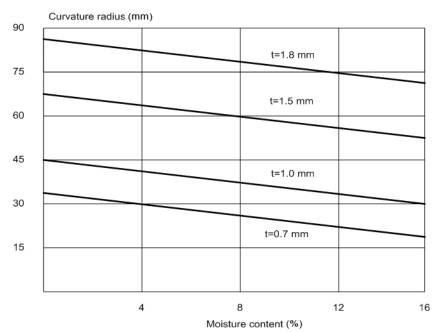

Fig. 5: Influence of moisture content and veneer thickness upon the curvature radius of the beech species.

There are numerous influencing factors for the curvature radius and bending capacity, which can include wood species, face-backside, thickness, moisture content, temperature of veneers, adhesives and adhesion, etc. These factors can be analyzed individually or in groups. A first conclusion but not the most important is that the wood species influences, by its density, the curvature radius and bending capacity. With the increase in the density of species the radius curvature of veneers will increase (Fig. 5), because the wood species is denser and will therefore decrease the ability of these veneers to be used for molded products with small radii. This rule is applied only to broad leaved species with diffuse pores (beech) and it is not applicable to softwood species with large differences between early and late wood areas of annual rings (i.e. spruce is not used for molded products or for curved products with small radii).

The main factor of influence for curvature radius is veneer thickness; with the increase of thickness the veneer's bending ability decreases. The beech veneers of 4 different thicknesses used in the experiments show that with the increase of thickness, the curvature radius will also increase and that will decrease the ability for bending. It was noted (Fig. 5) that when there is an increase in thickness from 0.7 to 1.5 mm at MC= 8 %, the increase of curvature radius is very significant, namely from 26 to 60 mm. This means that, with an increase in thickness of 1 mm, the curvature radius of veneers will increase by over 162 %. Fig. 5 is obtained using beech veneers, having 10 samples for each of the 4 thicknesses and for each of the 5 moisture contents. Thus we obtained 20 main points, which determine 4 linear equations, one for each thickness of veneer taken into consideration.

The extension of the thickness and moisture influence (beyond the existing data from Fig. 5) can be performed in two ways. Primarily by linear interpolation, other lines can be drawn on the graph shown in Fig. 5, to find the curvature radius for other thicknesses than are not indicated in the chart. For other moisture contents higher than 16 % the chart can be extended, although in actual fact this option is not real because the moisture content of adhesion will increase and consequently the adhesive bond between veneers will decrease drastically. The second method is mathematics, which starts from the fact that in a plane rectangular axis system (R_cOM_c) there are 4 parallel lines with classic representation $R_c = m \cdot M_c + n$ ($y = m \cdot x + n$). To arrive at this form of the equations, all 4 eq. from the chart are written by 2 points (Tab. 3) and afterwards the linear equations are found.

Tab. 1 notes that if it is analyzed a veneer of 0.7 mm thickness, the coefficient of linear equations *n* will be 34 and when the thickness is 1.8 mm, the coefficient *n* will be 86, which means that for a tenth of a 1 mm thickness the variation of curvature radius will be 4.7 mm. So, the overall equation derived by the generalization of previous equations will be:

$$R_c = -M_c + 47 \cdot t \qquad \text{(mm)} \qquad (2)$$

Eq. (2) is used for all values of moisture content and thickness of veneers. For example, if moisture content is 11.5 % and veneer thickness is 1.15 mm, the value R_c is obtained by direct replacement and it will result: $R_c = -11.5+47 \cdot 1.15 = 42.55$ mm.

In the case of real wooden pieces, firstly the real moisture content of glued veneers and all radii of curvature have to be identified and then the smallest radius will be retained as the most dangerous.

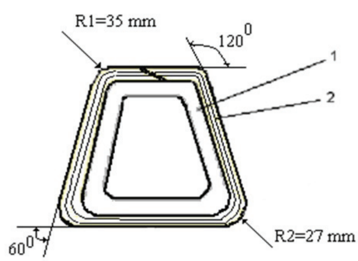

Fig. 6: Achieving the chair belt: 1-device; 2-chair belt made of veneers.

$$R = min\ \{R_1, R_2, R_3,\ldots,R_n\} \quad (3)$$

Finally, the required thickness is found.

$$T_{max} = (R_c+M_c)/47 \quad (4)$$

In the case of a chair frame (Fig. 6), it will be noted that R=27 mm and if the veneers' moisture content is 10 %, the maximum thickness will be t_{max}= 0.78 mm. Therefore during the chair belt achievement a veneer having a thickness of 0.7 mm was used.

CONCLUSIONS

According to the main objective of the paper, a method was devised in order to remove defects from molded products. Thus, the curvature radius and bending capacity of three species of veneer (beech, oak and spruce), the main factors of influence (specie, thickness and moisture content) and other foreseeable factors (temperature, etc.) were determined. Generally, temperature has a positive effect, but should be used sparingly, in order to obtain low temperatures and not carbonize corners and edges with a small radius of curvature. With the increase of veneer moisture, the curvature radii decrease, allowing small curves and diversified product forms. To avoid the inconvenience of superficial burns in the shallow edges, the wetting of small radii is recommended.

Experiments revealed that for pressing molded items of furniture it is recommended to use 0.7 to 2.5 mm thick veneers. Veneers thinner than 1.0 mm (usually aesthetical) are used for surfaces and the remaining thicknesses (1.0-2.5 mm) are used for the core layers, depending on the curvature radius (namely 1.0-1.5 mm for 37-60 mm curvature radius and 1.5-2.5 mm for bending radii larger than 60 mm).

This paper comes in support of the activity of manufacturers of molded products made of veneer, providing minimal data for choosing adequate veneers. Hence the defective items will be kept to a minimum and the quality of molded products will be better.

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