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THE PHYSICAL-AND-MECHANICAL MODEL OF WOOD DEFORMATION IN THE PROCESS OF BENDING AND PRESSING

Various techniques for obtaining curved wood members from solid wood were analyzed, also the influence of wood properties on its deformity in the processes of bending and pressing was investigated, obtained were the dependences for calculating the degree of wood compaction as well as relationships between a test bar thickness and its length in bending.
Keywords. Bending, pressing, compressive strain, tensile strain, steaming, cooking, solid wood.

Curved members from solid wood can be produced by two radically different ways:

- by way of carving (sawing out) shaped blanks during which a great amount of residue is produced and the fibers cutting occurs, which considerably lowers the wood strength;
- by way of bending a straight bar into shape by using a special template and allowing it to dry in its new shape.

Both of these methods are of practical use, they have their advantages and disadvantages. Obtaining curved members by method of bending requires more complicated techniques and equipment compared to carving. However, the material subjected to bending fully retains its strength or, in some instances, the strength tends to increase. The bent wood can be worked like any normal unbent wooden parts. The nature of physical processes that take place during bending is as follows: the process of bending any body involves the production of transverse stresses (normal-to-cross section stresses) within the limits of elasticity: tension on the convex surface and compression on the concave surface. Between the zones of tension and compression, there is a neutral layer the normal stresses in which are equal to zero. Since the values of normal stresses vary over the cross-section, there develop shear stresses that tend to cause adjacent layers of the body to slide parallel in opposite directions, but such slide is impossible, therefore the bending is inevitably accompanied by tension on the convex surface and compression on the concave surface of the woodwork [1-13].

The amount of tensile and compressive strains is dependent on the bar thickness and the bending radius. Let us assume that a bar of rectangular cross-section is bent in an arc of the circle, then the amount of deformation in the bar is in direct proportion to the stresses with the neutral layer being in the interior of the bar.

Let us denote the bar thickness by S, the initial length by L_0, the bending radius along the neutral line by R. The bar length along the neutral line during bending remains constant. It is equal to

$$L_0 = \pi R(\varphi / 180), \tag{1}$$

where φ is the bending angle expressed in degrees.

The face layer will show an increase in its length, this elongation being ΔL. The total length of the stretched portion of the bar is determined by expression

$$L_0 + \Delta L = \pi (R + h/2)\varphi / 180. \tag{2}$$

On deducting the preceding equation (1) from this one (2) we obtain the absolute elongation value:

$$\Delta L = \pi (h/2)(\varphi / 180). \tag{3}$$

The relative elongation ε_p is equal to $\Delta L/L_o = S/2R$, that is, the relative elongation $\Delta L/L_o$ in bending is dependent on the ratio of the bar thickness to the bending radius. The higher this ratio, the greater thickness of the bar S and, accordingly, the smaller bending radius R. Similar ratio for the relative compression value in bending process can be obtained in the same way.

If a bar of initial length L_o is bent round a radius R, in this case the maximum compressive and tensile strains are achieved. By denoting the amount of allowable compressive strain along the grain by ε_{cm} and the amount of allowable tensile strain along the grain $\varepsilon_{розт}$, we can write the ratio for the stretched side of the bar

$$L_1 = L_0(1+\varepsilon_{розт}) = \pi(R' + S)\,\varphi/180. \quad (4)$$

Yelding, $$R' + S = [L_0(1+\varepsilon_{розт})]/\,\pi\,(\varphi/180). \quad (5)$$

For the compressed (concave) side

$$L_2 = L_0(1-\varepsilon_{cm}) = \pi\,R'\,(\varphi/180), \quad (6)$$

or $$R' = [L_0(1-\varepsilon_{cm})]\,/\,\pi\,(\varphi/180). \quad (7)$$

By deducting the second equation from the first one, we obtain

$$S = [L_0(\varepsilon_{розт} + \varepsilon_{cm})]\,/\,\pi\,(\varphi/180). \quad (8)$$

By using the ratio *S/R* that characterizes the bending limit of wood for this case, we obtain $$S/R' = (\varepsilon_{розт} + \varepsilon_{cm})\,/\,(1-\varepsilon_{cm}). \quad (9)$$

By substituting the values of allowable compressive and tensile strains ($\varepsilon_{розт}$ and ε_{cm}), into the expressions obtained, we can determine the greatest possible values of S/R′ for various wood species. This ratio limiting values are obtained experimentally: for beech – 1/2.5; for oak – 1/4; for birch – 1/5.7; for spruce – 1/10; for pine – 1/11.

The common practice is that wood needs to be bent at the ratio greater than 1/3. From the data presented, one can see that coniferous species and part of soft broadleaved species are not suitable for bending to small curvature radii even if full advantages are taken of possible compressive and tensile strains. Rejects that occur in the process of bending coniferous and soft broadleaved wood species, result from ripple formation on the concave side due to nonuniform compression along the grain and low resistance to compression perpendicular to the grain. A perfect bend of a bar is only possible to the point where the amount of relative elongation of stretched layers or the amount of relative compression of compressed layers do not exceed the limit values for a given material. The above obtained ratio holds true for the materials whose tensile and compression strengths are equal. If the compression strength of the material is higher than the tensile strength, the neutral line will shift to the concave side. If the tensile strength is higher than the compressive strength, the neutral line will shift to the convex side, which is the case in the wood. In the example of an uncontrolled bending, the wood failure occurs due to rupture of the surface stretched layers. This is attributable to the fact that the allowable amount of tensile strain in wood is very small, no more than 1…2%, whereas the limit value for the compressive strain makes up 15…25 %.

The bending property of wood can be enhanced by cooking or steaming. Such treatment adds plasticity to wood. Wood cooking lowers the compressive resistance by a factor of two or more while the amount of shrinkage is increased. The tensile strength and deformity of wood are affected but slightly. For example, in steam-seasoned beech wood at moderate compressive resistance level (about 23 MPa) and the allowable compressive strain of 30%, the amount of possible tensile strain remains insignificant even with high amount of stresses (2% at 130 MPa). This is a limiting factor to bending properties of steam-seasoned wood and does not allow for taking full advantage of its ability to take considerable amounts of compressive strain. The bending properties of steamed wood are restricted by small amount of allowable tensile strain, the bend being limited to the ratio of approximately S/R ≤ 1/30. The bending properties of wood can be significantly enhanced when the property of steamed wood such as the ability to fully take a considerable amount of compressive strain, is taken into account.

Pressing is one of the currently used method of mechanical processing of wood. It is based on the application of force to wood using its plastic properties, wood is subjected to pressing for the purpose of obtaining complex shapes or compaction. Pressing is widly used to produce decorative wooden profiles for application in furniture making instead of non-ferrous metals thus saving them for machine engineering and electric power industry. Physical and mechanical characteristics of pressed wood are higher compared to genuine wood. Pressing is characterized by the degree of compaction which is determined by the ratio of woodwork dimensions prior to pressing and after pressing. The degree of compaction is calculated by the formulas:

$$\varepsilon = (h_n - h_\kappa) / h_n , \tag{10}$$

$$\varepsilon_0 = (h_n - h_\kappa) / h_\kappa , \tag{11}$$

where: ε and ε_0 – the degrees of compaction that are determined for initial or final dimensions; $h_п$, $h_к$ – the woodwork dimensions prior to and after pressing.

The given characteristics of the degree of compaction are related to one another by the ratio

$$\varepsilon_0 = \varepsilon / (1 - \varepsilon) \quad \text{i} \quad \varepsilon = \varepsilon_0 / (1 + \varepsilon_0) . \tag{12}$$

Since the mass of the woodwork during the pressing process and the mass of the woodwork obtained after pressing remain practically the same, the degree of compaction can be defined as a ratio of the wood density after pressing to the density prior to pressing

$$\varepsilon = (\rho_\kappa - \rho_n) / \rho_\kappa , \tag{13}$$

where $\rho_к$ and $\rho_п$ – final and initial values of density.

Sometimes the degree of compaction is expressed in percent. Commonly, wood pressing is done to a 40 % degree of compaction. Wood is more amenable to across-the-grain pressing after steaming which enhances its plasticity. Wood's plasticity increases at moisture content of about 30 % and elevated temperature up to 160 ºC. Higher temperatures cause wood pyrolysis. The stabilization of the shape obtained during the process of pressing is provided by cooling followed by drying when the moisture content is higher than 12 %. Pressing of wood involves deformation of its cells. Three phases of deformation can be observed here. Initially, the wood is in the stage of elastic deformation, the cells compression, ε, being equal to about 6 %. In the second stage of pressing, the thin walls of cells are destroyed - this is the stage of plastic deformation with ε being equal to 6 to 30 %; in the third stage, with ε ranging from 30 to 40 %, thicker walls of the cells are being destroyed that were deformed in the second stage. The types of pressing are distinguished by the direction of the acting forces: flat-uniaxial, profile, and volume-hydrostatic. The dependence of deformation on stresses during the process of pressing is analytically expressed by the formula: $\varepsilon_{cm} = \sigma / E + (1/\eta)\,(\sigma^2 / \upsilon)$, (14)

where: $\varepsilon_{ст}$ – compressive strain; σ – stress; E – modulus; η – coefficient of toughness; υ – loading rate.

By analyzing the above dependence, one can note that the degree of compaction tends to increase with increase in stresses, and decreases with increasing modulus of elasticity, toughness and loading rate. Flat and profile pressing are the most frequently used types of pressing today. The flat pressing can be done with the use of a mould that confines the shape of the woodwork being pressed or without it. The amount of pressing force is determined by the size of the woodwork as well as by the required degree of compaction. The force required for pressing without a mould is calculated by the formula $P = b \cdot l \cdot \sigma_x$, (15)

where: *P* – required pressing force; b is the woodwork width; *l* – the woodwork length; σ_x – the resistance of wood to pressing, it is dependent on the degree of compaction and wood species. The value of σ_x is determined by empirical equation $\sigma_x = k \cdot e^{m\varepsilon}$, (16)

where: k, m – coefficients which are dependent on wood species (for pine – k = 1.6, m = 0.007; for spruce − 1.19 and 0.07 respectively; for aspen – 0,45 and 0,09); e – base of natural logarithms; ε – degree of compaction.

If pressing is carried out with the use of a mould, it is necessary, when calculating the force, to take into account additional force required to overcome wood-to-metal friction. In the case of profile pressing, account must be taken of the pressing force and force for moving the woodwork in the receiver. The force required to move the woodwork into the receiver is defined as frictional force with consideration for compressive pressure and coefficient of friction.

Conclusions. The study presented in this paper indicates that wood deformity in bending and pressing is influenced by the following factors: wood species (its micro- and macrostructure), the direction of force action in relation to the grain, the age and moisture content of the wood, the methods of cooking or steaming to impart plasticity, and other physical and mechanical properties of wood.

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УДК 674.047

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Фізико-механічна модель деформації деревини в процесах гнуття і пресування

Встановлено, що в процесі гнуття будь-якого тіла в межах пружних деформацій виникають нормальні до поперечного перерізу напруження: розтягу на випуклій поверхні і стиску на ввігнутій стороні. Оскільки величина нормальних напружень змінюється по перерізу, то виникають напруження сколювання, які стараються зсунути одні шари деталей відносно інших. Для підвищення здатності деревини до гнуття застосовують гідротермічну обробку: проварювання в гарячій воді або пропарювання. Така обробка робить деревину більш пластичною. Пресування засноване на силовій дії на деревину з використанням її пластичних властивостей. Пресують деревину для отримання: декоративних деталей в меблевій промисловості; матеріалів, які заміняють кольорові метали в машинобудуванні; ізоляційних матеріалів в електротехнічній промисловості. Деревина піддається пресуванню легше поперек волокон після гідротермічної обробки, яка підвищує її пластичність. Деревина стає більш пластичною за вологості біля 30 % і підвищеною температурою – до 160 °С.

Ключові слова: гнуття, пресування, теплова обробка, нагрівання, масивна деревина.