

Shevchenko S.A.
State Biotechnological
University,
Kharkiv, Ukraine
E-mail:
serg.shevchen@btu.kharkiv.ua

**RESEARCH INTO THE INFLUENCE OF
SWIRLING WOOD GRAIN ON WOOD
SPLINTERING AT MILLING FINGER JOINT
ELEMENTS**

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Shevchenko S.A. Research into the Influence of Swirling Wood Grain on Wood Splintering at Milling Finger Joint Elements

Abstract. *The object of the study is the influence of swirling wood grain on wood splintering at milling finger joint elements. The study was carried out on the example of jointed cladding slats made of larch wood, used for the exterior finishing of the entrance group of a building.*

To conduct the study, photographs were taken of the slat joint areas that exhibit defects in tenoning operation (wood splintering) and, for comparison, those without such defects were used. The photographs were imported into the CAD, where the angle of annual growth ring deviation was measured. Subsequently, a statistical analysis of the measurement results was carried out. Processing of the measurement results using the least squares method made it possible to obtain the regression dependence of the probability of wood splintering on the angle of annual growth ring deviation near a knot.

Keywords: *finger joint, tenoning, knot, annual ring, angle, splintering, probability, regression dependence.*

Шевченко С.А. Дослідження впливу завитків волокон деревини на її сколювання при фрезеруванні елементів зубчастого шипового з'єднання

Анотація. *Об'єктом дослідження є вплив завитків деревних волокон поблизу сучків на сколювання деревини при фрезеруванні елементів зубчастих шипових з'єднань. Такі з'єднання дедалі ширше використовуються при виготовленні столярно-будівельних виробів і клеєних дерев'яних конструкцій (зокрема, багатошарових дерев'яних поперечно-клеєних панелей), тож важливо контролювати частоту виникнення зазначених вад нарізання шипів. Метою дослідження є визначенням регресійної залежності ймовірності сколювання деревини від кута між річним шаром і повздожньою віссю рейки. Дослідження було виконано на прикладі зрощених рейок обшивки з деревини модрина, використаних для зовнішнього оздоблення вхідної групи будинку.*

Для здійснення дослідження було сфотографовано місця зрощування рейок, які мають вади нарізання шипів (сколювання деревини) та, для порівняння, не мають таких вад. Фотографії було перенесено в САПР, де й були позначені зубчасті шипи та вимірні кути відхилення річних шарів. Далі було здійснено статистичний аналіз результатів вимірювань із визначенням регресійної залежності ймовірності сколювання деревини від кута відхилення річного шару. Для цього спочатку виконано структурну ідентифікацію шуканої залежності. Обробка результатів вимірювань із застосуванням метода найменших квадратів дала змогу отримати регресійну залежність ймовірності сколювання деревини від кута відхилення річного шару поблизу сучка.

Ключові слова: зубчасте шипове з'єднання, нарізання шипів, сучок, річний шар, кут, імовірність, регресійна залежність.

The topicality of the problem

The aspiration to utilise timber as fully as possible and the high requirements imposed on wood products (which exceed the properties inherent to solid wood) lead to an increasingly frequent use of wood bonding technologies. In this process, unacceptable wood defects (primarily knots) are removed by longitudinal sawing of boards and, at the subsequent stage, by cross-cutting of slats. However, a known phenomenon with a small distance between the cutting location and a knot is wood splintering during subsequent milling of the finger joint elements in the zones of wood fibre swirl. Conversely, if the distance between the cutting location and the knot is too large, part of the defect-free wood area will not be utilised for the manufacture of glued products.

Therefore, there is an actual need for a rational selection of the cutting location when removing knots from slats, in order to prevent both excessive wood consumption and wood splintering during milling of finger joint elements.

Analysis of recent researches

In study [1], cutting forces during cross-cutting of wood were investigated in order to identify risks and factors influencing the wood splitting process. The research was carried out using examples of sawing Norway spruce wood with two types of circular saw blades: high-speed steel blades and blades with carbide-tipped teeth. The experimental results show that cutting conditions (cutting speed and feed rate) affect the magnitude of cutting forces to a significantly lesser extent than the wear of the saw blade teeth. The research findings are confirmed by an analysis of cutting forces during wood cutting using the finite element method.

Article [2] presents the results of modelling the processes of wood splitting and chipless cutting of *Pinus sylvestris* L. from the standpoint of tool geometry design and machine driving force. The corresponding processes were analysed using tools of various shapes: simple, refracted, concave and convex wedges. The investigated types of splitting or chipless cutting include chipless cutting across the grain, splitting along the grain, radial splitting, and tangential splitting.

The results of studies on the cross-cutting of wood with circular saws are presented in article [3]. The influence of cutting edge geometry, wood species, circular saw type and cutting conditions on the cross-cutting process was investigated with the aim of reducing production costs and saving energy. Given the similarity between the operating conditions of the laboratory setup and those of industrial equipment, the obtained results can be applied in the design of woodworking machinery.

In study [4], a three-dimensional paradigm describing the geometry of knots and the associated distortions of wood fibre directions was proposed. This paradigm makes it possible to determine the three-dimensional orthogonal components of fibre directions in the stem. The paradigm generates fibre orientation around a knot at any position within a log or sawn timber, with a predicted fibre texture in planes parallel to the longitudinal direction, as well as fibre textures in radial and tangential directions. These textures are obtained based on physical constraints related to fibre growth within annual growth ring surfaces and taking into account knot formation theory. In this case, the knot axis may be non-linear, and the knot cross-section may be oval.

The aim of study [5] was to develop and apply a laboratory method for assessing the geometry of annual growth rings and determining fibre orientation in a high-resolution 3D grid in wood samples containing knots. The laboratory method was based on optical scanning (to obtain surface images) and laser scanning (to determine fibre inclination angles) on high-

resolution grids of the scanned surfaces. By repeated planing of the material and subsequent scanning of newly exposed surfaces, 3D coordinates of fibre positions along different growth layers and the 3D orientation of fibres in a 3D grid were obtained. The research results can be used to calibrate parameters of fibre orientation models in the vicinity of knots, which is important for assessing the influence of wood fibre directions around knots on the strength of structural timber and sawn timber.

The aim of study [6] was to investigate and quantitatively assess the effect of fibre deviation in two dimensions and at different hierarchical levels on the tensile strength of thin birch veneer sheets, as fibre deviation is the dominant factor affecting their ultimate tensile strength. The microfibril angle was assessed using wide-angle X-ray scattering..

The purpose of the research

The purpose of this work is to investigate the influence of wood fibre swirl on wood splintering during milling of finger joint elements.

Accordingly, the objectives of the study are to develop a methodology and to conduct an experimental investigation to determine the regression dependence of the probability of splintering on the angle between the annual growth ring and the longitudinal axis of the slat.

Research methodology

The research was carried out using examples of jointed cladding slats made of larch wood, used for the exterior finishing of the entrance group of a building in the city of Kharkiv (Ukraine), where they are protected from direct exposure to moisture and other atmospheric influences. The cladding slats have a protective lacquer coating. For joining the slats, finger joints with a length of 12,5 mm (taking into account their blunting) were used; the finger pitch was 4 mm.

To conduct the study, photographs of the slat joint areas that exhibit defects in tenoning operation (wood splintering) and, for comparison, those without such defects were used.

The photographs were imported into the LibreCAD system, where the finger joints were marked and the angle of annual growth ring deviation was measured.

Subsequently, a statistical analysis of the measurement results was carried out to determine the regression dependence of the probability of wood splintering on the angle of annual growth ring deviation.

Research results

Photographs of finger joints are shown in Figs. 1–2. In these figures, for example, some angles of annual growth ring deviation are marked. In total, 74 annual growth ring deviation angles were measured, and wood splintering was observed in 12 finger joint elements.

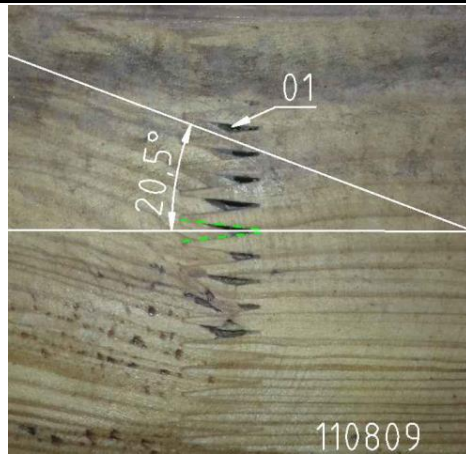


Fig. 1 – Finger joint with defects in tenoning

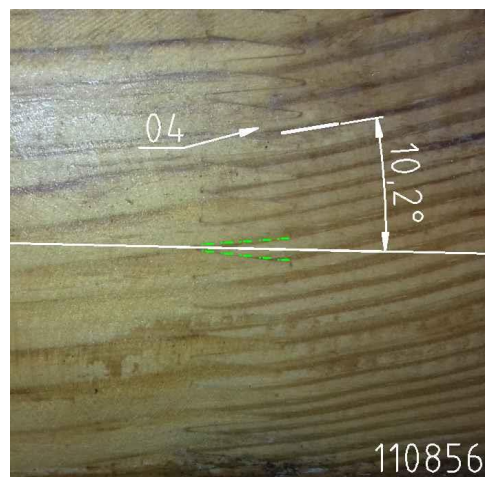


Fig. 2 – Finger joint without defects in tenoning

Fig. 3 shows a diagram illustrating the results of measurements and observations of wood splintering during milling of finger joint elements (absence of splintering is denoted as 0, and presence of splintering as 1).

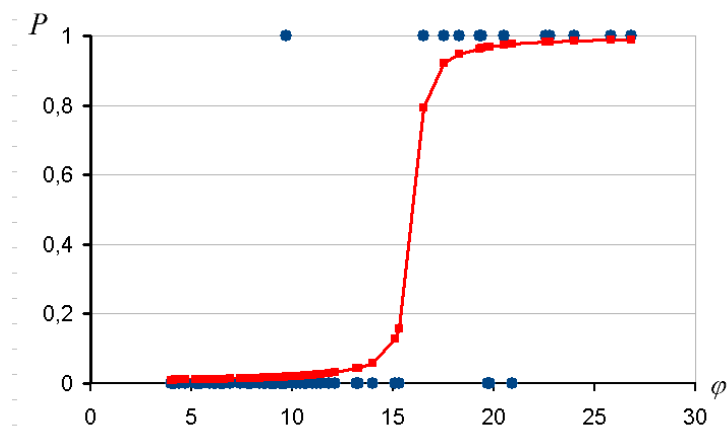


Fig. 3 – Measurement results and regression dependence

The experimental results are considered as a realisation of a random function whose values correspond to the probability of wood splintering during milling of a finger joint element. A nonlinear regression function is constructed to characterise the dependence of the

mathematical expectation of wood splintering during milling of a finger joint element on the angle between the annual growth ring and the longitudinal axis of the slat.

To construct the nonlinear regression, a function of the form (1) is used, characterised by the presence of two horizontal asymptotes

$$y(\varphi) \sim \arctg(\varphi) \quad , \quad (1)$$

where y is the nonlinear regression function; φ is the angle between the annual growth ring and the longitudinal axis of the slat, degrees.

Structural identification of function (1) is performed so that its range lies between zero and one, which corresponds to zero probability of splintering at small angles of annual growth ring deviation and unit probability at large angles of deviation.

For this purpose, first, function (1) is scaled so that the range of its values changes from π to unity. Second, a shift along the abscissa axis is added to function (1) so that the mean value of the domain equals 1/2. These transformations correspond to function (2):

$$y(\varphi) = 0,5 + \frac{1}{\pi} \arctg(\varphi) \quad . \quad (2)$$

The next step is to adjust the sensitivity of function (2) to changes in the argument (i.e. its first derivative) and the shift along the abscissa axis (which is a common practice in artificial neural networks etc. [7]). For this purpose, a constant term and a scaling coefficient of the argument are entered to function (2):

$$P(\varphi_0, k, \varphi) = 0,5 + \frac{1}{\pi} \arctg(\varphi_0 + k \varphi) \quad , \quad (3)$$

where P is the probability of splintering; φ_0 constant term, degrees; k is the scaling coefficient.

For parametric identification of the regression dependence (3), the least squares method is used. Thus, the square of the difference between the value of function (3) and the measurement result at the corresponding value of the angle between the annual growth ring and the longitudinal axis of the slat is calculated, and the sum of squares is minimised:

$$\sum_{i=1}^n (S(\varphi_i) - P(\varphi_0, k, \varphi_i))^2 \rightarrow \min \Rightarrow \varphi_{0,r}, k_r \quad , \quad (4)$$

φ_0, k

where i is the measurement index; n is the number of measurements; S is the indicator of presence/absence of splintering (takes values 1 or 0, respectively); $\varphi_{0,r}$ is the rational value of the constant term, degrees; k_r is the rational value of the scaling coefficient.

The numerical solution of the extremum search problem (4) was carried out in a spreadsheet. As a result, the following regression equation was obtained for the dependence of the probability of wood splintering during milling of finger joint elements on the angle of local deviation of annual growth rings from the longitudinal axis of the slat:

$$P(\varphi) = 0,5 + \frac{1}{\pi} \arctg(-42,1 + 2,63 \varphi) \quad . \quad (5)$$

The regression graph (5) is attached to the measurement results (Fig. 3).

Conclusion

1. Function (3) can be used to approximate the nonlinear regression dependence of the probability of wood splintering during milling of finger joint elements on the angle of annual growth ring deviation.

2. Processing of the measurement results using the least squares method made it possible to perform parametric identification of dependence (3) and obtain the regression dependence (5).

3. The proposed methodology for determining the dependence of the probability of wood splintering during milling of finger joint elements on the angle of annual growth ring deviation is advisable for use in developing requirements for knot removal and in substantiating the parameters of algorithms for automatic wood defect removal lines equipped with machine vision system or other non-destructive wood testing system..

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