EXPERIMENTAL RESEARCH AND MODELLING OF COMPOUND PARAMETERS WITH MINI TINES ON STRETCHING STRENGTH AT LENGTHENING OF MASSIVE WOOD

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ABSTRACT*: In this work is presented a mathematical model of influence in compound parameters at lengthening of massive wood with mini tines on firmness of compound. Influental parameters are density of the wood (ρ), relation of width and thickness of the wood (b/h) and geometrical sizes of mini tines(tooth) expressed with the relation of height and width of the tooth (l/t). Output size, as a referent for the firmness of the glued compound is the size of compound firmness (strength), which is measured to the critical force of breakage on a Testing Machine (50kN).*
Results of experiments may serve in a direct application of extended (lengthened) wood with mini tines in a specific finished products. Mathematical model is applicable for calculation of breakage force and in other wood species.

1. INTRODUCTION

By testing of massive wood connected with tines on firmness of stretching we determine its firmness, durability, quality and other features for precisely defined usage. There is a wide range of use of lengthened massive wood either as basic construction elements or finished products. Their different working terms due to mechanical, thermal, chemical and other effects require wood of such characteristics, that will have required firmness (hardness), durability, safety and effective cost.
Today, tines joining techniques are massively accepted in the industrial production. That way, people want to ennoble wood materials which in new construction forms has improved physical and mechanical properties compared to massive wood. Its predicted that length connection massive wood elements will maintain a significant spot in wood industry beacuse of the complicated demands for shaping contemporary construction solutions that contribute a higher utilization of wood materials, their rational manufacture and application in development of high quality products. Firmness of glued toothed compounds is one of the most important technical properties of lengthwise glued elements. Therefore, a special attention has to be dedicated to the right choice of toothed compound. Firmness of the glued compounds depends on several influential parameters, such as:

- geometry of the tooth,
- position (orientation of the compound considering the compound plane, that is, vertically, horizontally or under and angle where the smallest tensions are under the angle of 45 °)
- tipe of material and its properties (volume density, quality and humidity within 6 – 14% , which has a great impact on glue),
- quality of tines making,

- tipe of glue and its properties,
- technological parameters important for hardening of the glue (temperature and pressure),
- terms of use.

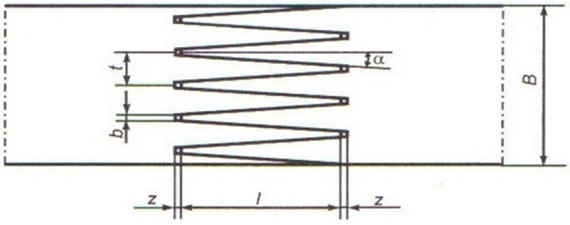

Figure 1. Parameters of the wedge – toothed compound

Lengthening with wedge tines is technologically the most advanced and there is a very wide range of applications in the wood industry. Wedge tines are mostly glued and their advance among other forms of lengthening with tines is reflected in its high bond strength in use of elements width from 150 mm, with a slight seizure of wooden mass for the making of wedge-toothed composition.

2. PURPOSE OF RESEARCH

The purpose of experimental research and mathematical modelling is examination of significance of variable factors of toothed compound: geometry of the tooth, expressed with the relation of height of the tooth(l) and the width of the tooth (t), relation of width (b) and the thickness (h) of the element which is extended and the volume mass(ρ) of the massive wood which is extended with mini tines. Based on the results of the experiments modelling the process, that is, the force of stretching by the application of the multiple factor mathematical model $N = 2^k$. In 8 experiments, with three repetitions in every point of the experiment plan is modeled an optimal area of the chosen factors of the massive wood lengthening process (X_1= l/t, X_2= b/h, X_3=ρ) and obtained a matematical model of the influence of process chosen factors, which is appliable on the lengthening processes of different kinds of massive wood.

3. MATERIAL, EQUIPMENT AND DEVICES

3.1. Material

In the experiment are used beech and oak elements for lengthening whose average volume mass is 680 kg/m^3 for beech, and 720 kg/m^3 for oak elements. For lengthening of mass wood is used a compound with wedge mini tines, whose geometrical relation l/t was 2,5 mm/mm, and 3,5 mm/mm, while the relation of width and thickness of the elements b/h was 1,87 mm/mm, and 2,15 mm/mm. Average humidity of the testing elements was in the range 7-9 %. Lengthening of the wood was performed in a company named d.o.o „Vrbas“ Banja Luka on the line for lengthening german equipment manufacturer „Weinig“ by using one-component waterproof glue Kleibert 300.0, that meets the demanding standards of the glue quality EN 204.

3.2. Equipment and devices

Testing strength firmness to the critical point of breakage of the testing elements was done in in the Faculty of technical engeneering in Bihać using a Testing maschine SIL-50KNAG, by a manufacturer SHIMADZU (figure 2.)

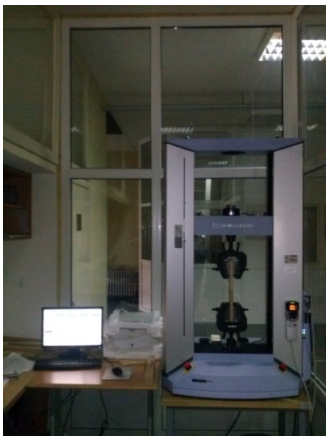

Figure2. Testing machine SHIMADZU SIL-50KNAG

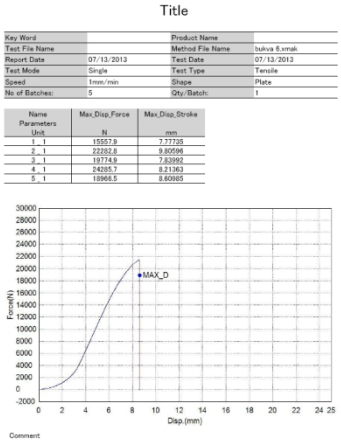

Figure 3. Display of breakage force on a beech testing element

Figure 3. shows a result of breakage force measurement of the beech testing elements in the experiment No. 6. which is displayed on the computer of the Testing machine tipe SIL-50KNAG.

4. PLAN OF EXPERIMENTS

Formalized state, description of the real process of massive wood lengthening is defined by the next sizes:

a) Input sizes - geometrical sizes of the tooth, *l/t* (mm/mm),
- relation of the width and the thickness of the testing element, b/h (mm/mm),
- density of the wood ρ (kg/m^3).

b) Outputsize: Force of stretching F (N)

c) Function of the process state: F = f (l/t, b/h, ρ).

Graphic display of input – output sizes is available on the figure 4.

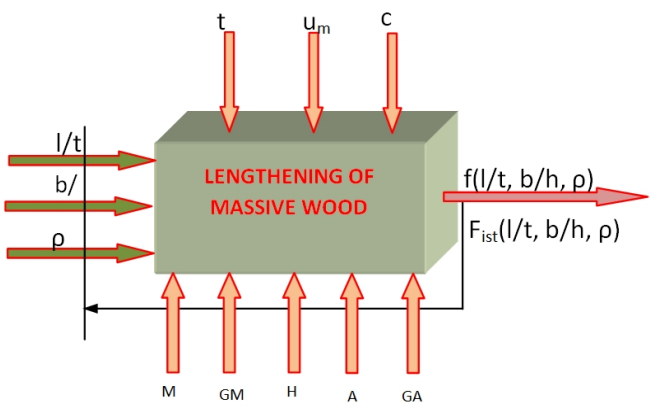

Figure 4. Input – output sizes of the convective drying process

The force of stretching can be displayed in the form of expression:

$$F_{ist} = C\,(l/t)^x\,(b/h)^y\,\rho^z \qquad (1)$$

After logarithming of the expression (1) we get a general linear form :

$$y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 \qquad (2)$$

and then: $y = \ln F_{ist}$, $b_0 = \ln C$, $b_1 = \ln (l/t)$, $b_2 = \ln (b/h)$, $b_3 = \ln \rho$

Matrix of the experiment plan $n = 2^3 = 8$ and experimentally obtained values of the stretching force are displayed in the table 1.

Table 1. Matrix of the experiment plan

Number of exp. N_j	Mtrix of coded values			Physical values			Results of stretching force measurements			Average value	
	X_1	X_2	X_3	l/t	b/h	ρ	F_1	F_2	F_3	Y_{sr} ($\bar{y}_j^F$)	ln $\bar{y}_j^F$
	-	-	-	-	-	kg/m^3	N	N	N	N	-
1	-1	-1	-1	2,25	1,87	680	17814,5	17332,7	16746,6	17297,93	9,758
2	+1	-1	-1	3,25	1,87	680	18411,2	20104,1	19451,7	12844,91	9,869
3	-1	+1	-1	2,25	2,15	680	19451,7	16413,6	21234,0	19033,10	9,853
4	+1	+1	-1	3,25	2,15	680	21038,1	21607,4	17999,4	20214,96	9,914
5	-1	-1	+1	2,25	1,87	760	6412,13	20296,2	15403,7	14037,34	9,549
6	+1	-1	+1	3,25	1,87	760	15557,9	22282,8	19774,9	19205,20	9,862
7	-1	+1	+1	2,25	2,15	760	9294,1	17691,8	23484,4	16823,43	9,730
8	+1	+1	+1	3,25	2,15	760	18211,6	22270,7	20918,1	20466,8	9,926

In the table 1. Is displayed a matrix of experiment plan $n = 2^3 = 8$ and experimentally obtained values of the stretching force.

based on an expression:

$$b_i = \frac{1}{N}\sum_{j=1}^{N} x_{ij}\bar{y}_j \;,\; i = 1,2,3,; \qquad (3)$$

Are calculated the coefficients of regression $b_0 = 9{,}807$; $b_1 = 0{,}085$; $b_2 = 0{,}048$ i $b_3 = -0{,}04$., that way mathematical model has a form of:

$$Y = 9{,}807 + 0{,}085\,X_1 + 0{,}048\,X_2 - 0.04\,X_3 \qquad (4)$$

5. PROCESSING OF THE EXPERIMENTAL RESULTS

Test of homogeneity of experiments, that is, one - gender is performed after a conducted experiment. Test of homogeneity of dispersion for a certain level of reliability (P=0,95) is done by the Cochran criterion.[1;4]

$$K_h = \frac{\max S_j^2}{\sum_{j=1}^{N} S_j^2} \le K_t\left(f_j, N\right) \qquad (5)$$

and then:

K_t – table value on Cochran criterion for the degree of freedom f_j i N
f_j – degree of freedom ($f_j = n_j - 1$)
n_j – number of repetitions in the pattern
N – number of samples
S_j^2- variance patterns

Considering that is: $K_t = (2,8) = 0,516 > K_h = 0,452$ the experiment can continue because the dispersion is homogenic.

Examination of significance of model coefficients :

$$S_y^2 = \frac{\sum_1^N \sum_1^n (y_{ji} - \bar{y}_j)^2}{f_z} = \frac{1,372}{16} = 0,0857 \quad (6)$$

$$S_b^2 = \frac{S_y^2}{Nn} = \frac{0,0857}{24} = 0,0035 \ldots S_b = 0,0597 \quad (7)$$

Considering that $S_b t = 0,1045$, the condition of coefficients significance is satisfied $|b_i| > S_b t$, because it`s :

$$|b_0| = |9,807| > 0.0345, |b_1| = |0.085| > 0.0349$$

$$|b_2| = |0,048| > 0,0345, |b_3| = |-0,04| > 0,0349$$

And then : $t_{(f_v,\varepsilon)} = t_{(f_E,\alpha)} = t_{(16,0,05)} = 1,75$

Checking the adequacy of mathematical model is done with a F- criterion :

$$S_a^2 = \frac{\sum_{j=1}^{N} n(\bar{y}_j^E - y_j^R)^2}{f_a} = \frac{8 \cdot 0,018877}{4} = 0,01490775 \quad (8)$$

Where we have f_a= N-k-1 =4

For $S_a^2 = 0,01490775 < S_y^2 = 0,0857$, we get $F_a = \frac{S_a^2}{S_y^2} = \frac{0,01490775}{0,0857} = 0,17395$

For the value $F_{t(f_a,f_E)} = F_{t(4,16)} = 3,01, criterion$ adequacy is satisfied because

$F_a = 0,17395 < F_t$=3,01

According to, obtained mathematical model (4) adequately describes the stretching force at lengthening of massive wood with mini tines. Decoding according to the formula:

$$X_i = 1 + 2\frac{\ln f_i - \ln f_{imax}}{\ln f_{imax} - \ln f_{imin}} \quad (9)$$

We get:

X_1 = 5,449 ln l/t -5,419; X_2 = 14,285 ln b/h -9,928; X_3 = 18,018 ln ρ -118,513

by integrating values X_1, X_2, X_3 in a mathematical model we get a model in natural sizes :

$$\mathbf{F = e^{13,611}\,(l/t)^{0,463}\,(b/h)^{0,685}\,\rho^{-0,72}}$$

respectively:

$$\mathbf{F} = \frac{781888,1846 \cdot (l/t)^{0,463} \cdot (b/h)^{0,685}}{\rho^{0,72}} \quad (10)$$

On the figure 5. are graphically presented comparative results obtained by measuring the stretching force with an experiment and calculated the value of the stretching force by the obtained mathematical model.

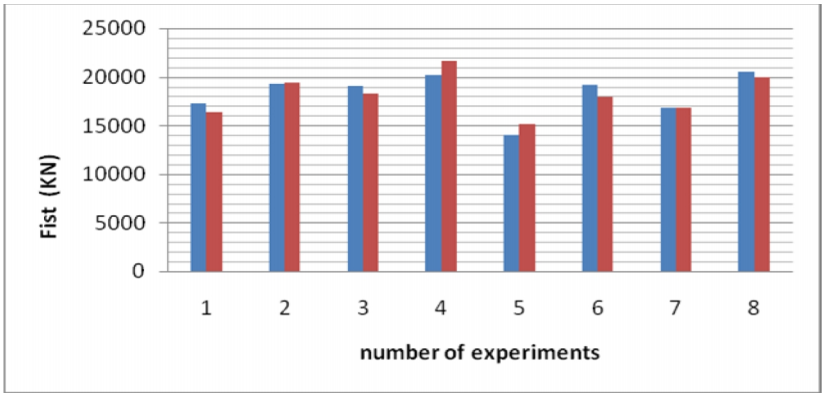

Figure 5. Comparative results of experiments

The diagram shows that measured stretching force by the experiment (Columns of blue) are approximate values calculated by the values which are calculated by a mathematical model (10) for the stretching force (Columns of red).

6. CONCLUSION

Experimental research and mathematical modelling of factors: geometry of the tooth (l/t), relation of the thickness and the width of the testing element (b/h) and the density wood ρ in the process of lengthening of massive wood with mini tines has shown that this factors significantly affect on the firmness of the glued compound.[3] By decoding a mathematical model was obtained (4) a mathematical interpretation of the influence of these factors (10) which will in the further research be optimized in a function of purpose that critical breakage force in stretching tends to the maximum.. Gaining optimal results for theese three factors we will get an optimal stretching force, which will in the further analysis have a scientific contribution to improve the current analytical expressions for the calculation of the breakage force in stretching the lengthened massive wood with wedge tines.

7. LITERATURE

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