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SURFACE SMOOTHING OF THE SIDES OF PRISM-SHAPED BEECH WOOD DETAILS VIA LAPPING WITH FAST-ROTATING METAL CYLINDER

Dimitar Angelski, Andrey Kavalov, Vladimir Mihailov
University of Forestry, Sofia, Bulgaria
e-mail: d.angelski@ltu.bg; andrey.kavalov@gmail.com; vladko86mihailov@gmail.com

ABSTRACT

The article presents and analysis the results from laboratory experimental researches over opportunity for effective surface smoothing of cutter-processed or initially sanded surfaces of prism-shaped steamed beech samples with grit number of a sandpaper № 80. The lapping is executed by a special work instrument – cylindrical steel circlet, loaded on the milling spindle. Upon handing over and further pressure of a detail to the smooth polished surrounding surface of the rotating bushing, the lapping that occurs results in smoothing of the detail's surface that has been in contact. It is also due to the partial heating, densification, decrease and rounding of the tops of the microgrades remaining after sanding. The purpose of the research has been to evaluate the degree of smoothing, by checking the multiple influence of the major factors on which it depends. In this particular case, we have chosen to vary the following factors: feed speed of detail U; radially directed force of pressing to the spindle q; number of impacts over the same surface n. The research results show that a quality smoothing, equal to the traditional one that is double sanded with sandpaper №180 or №240, can be reached at values of the variable factors, as follows: u = 8÷10 m.min-1; q = 6÷8 kN.m-1; n = 1÷2 impact. Apart from the quality smoothing, this lapping method results in further economy of sandpaper and lacquer of up to 20%.

Key words: surface smoothing, lapping, beech, lapping regime.

INTRODUCTION

The smoothing of wood surfaces in the manufacture of furniture with the participation of solid wood elements and natural veneers is an essential phase and an integral part of the technological process associated with the formation of film protective and decorative coatings. As is known, smoothing is a type of impact on finished wood surfaces in order to reduce the micro-irregularities to sizes and shapes that satisfy the requirements for the formation of quality and economically coatings. In production conditions, it is performed once or twice before and/or after curing of the first film-forming layer. In most cases, this effect is mechanical made and the results are in the removal of some of the peaks of micro gravities, when grinding with fine-grained sandpaper (from No. 180 upwards) or by irreversibly compressing them to lower levels when used is some of the so-called deformation smoothing.

Currently, two types of deformation smoothing methods are practically applicable: by thermal rolling and by lapping. The lapping of wood surfaces, including those of solid wood elements and any kind of veneered with natural veneers panels, is a specific type of impact on the treated surface, which is pursued by a transient pressure drag of a suitably shaped working instrument. Its active part is a solid, smooth projection with a defined radius of curvature that tightly contacts with the work surface. As a consequence, irreversible compression of the peaks of the micro-irregularities is achieved. Thus, they reduce their height and round to a state where they satisfy the regulatory requirements for the formation of quality film coatings (Kavalov at al., 2015).

The main advantages of lapping over sanding with fine-grained sandpaper are the following:

- There is no removal of micro-layers from the workpiece, which is benefit in order to avoid of the so-called "over sanding" defects when using thin veneers.
- There is no sanding dust, which significantly improves the working conditions and protect the environment from pollution;
- More than twice is reduced the specific consumption of mechanical energy for smoothing;
- Reduces to a minimum the amount of microfiber, thus eliminating "bristle" on the surface after hardening of the coating.

In addition, the compression of the outermost micro layer results in a thickening of the wood structure, which limits the penetration of liquid film forming compositions into depth. Thus, from 30 to 40 percent savings of paints and varnishes are achieved in the formation of coatings (Бухтияров, 1983). Compared to similar thermal rolling, lapping has two other practically proven advantages (Kavalov at al., 2015):

- There is no heat consumption for heating of the pressure rollers;

- Eliminates the risk of softening of adhesive layers, delamination and sticking of melting adhesives on the rollers;

- There are no conditions created for burning the smoothed surfaces and reducing the adhesive strength when working with polyester, polyacrylate and polyurethane varnishes.

Various methods and technical solutions are known for applying lapping as a method of smoothing the surfaces of solid wood components or veneered furniture panels. One of them is to use a metal (mainly steel) body with a smooth, rotationally shaped surrounding surface, to which the treated object is pressed and fed with radially directed force. Most suitable for this type of grinding are the surrounding surfaces of linear parts with prismatic or other, including profiled shape sections.

The advantages of this type of lapping are as follows:

- When the rotation profile of the workpiece exactly matches that of the workpiece, conditions are created to smooth the profile sections. In practice, this means that on every milling cutter can also be easily made a similar profile smoothing tool to affect the already milled surface;
- There is an opportunity to apply two methods of lapping. One - by pressing and sliding the processed object to a stationary, i.e. non-rotating lapping tool and the other - by its sliding during rotation of the tool.

These two variants of lapping significantly extend the possibilities for diversifying the conditions for its application. This can be accomplished as long as there is evidence of their applied effectiveness. This can be accomplished as long as there is evidence of their applied effectiveness. Possession of such information is possible, if appropriate experimental studies are carried out. This can be accomplished as long as there is evidence of their applied effectiveness. If experimental studies are conducted, such information will be available.

In the presented work, the results of a similar study were selected to report, which in this case concerns the smoothing of surrounding surfaces of prismatic workpieces. The smoothing is done by lapping with a steel cylindrical body with a smoothly machined surrounding surface, fixed to the spindle of a universal woodworking moulder. The purpose of the study is to determine the degree and quality of smoothing during rotational of the lapping tool by varying the values of the basic parameters of the lapping process.

MATERIAL AND METHODS

For the purposes of the experiment, prismatic beech samples with a cross-section size of 30/25 mm and a length of 500 mm were used. The prismatic form is done by longitudinally flat milling using a universal spindle moulder. Before lapping, the surrounding surfaces of the workpieces were sanded once on a sanding machine with a sandpaper with grit size 80, to achieve a roughness *Rm* from 44 to 56 µm. The smoothing is done using a specific method of lapping. The following features, further illustrated by the scheme shown in Fig. 1, characterize it. The working tool (4) is a cylindrical steel sleeve with a smooth surrounding surface ($Ra = 5 \pm 2$ µm) and an outer diameter of 50 mm. Its inner diameter corresponds to the diameter of the milling spindle (30 mm). The fixed cylindrical steel circlet during lapping is assumed to move counterclockwise at a frequency of ≈3000 min^{-1}, which is equal to 7 $m.s^{-1}$ peripheral rotational speed on its working surface.

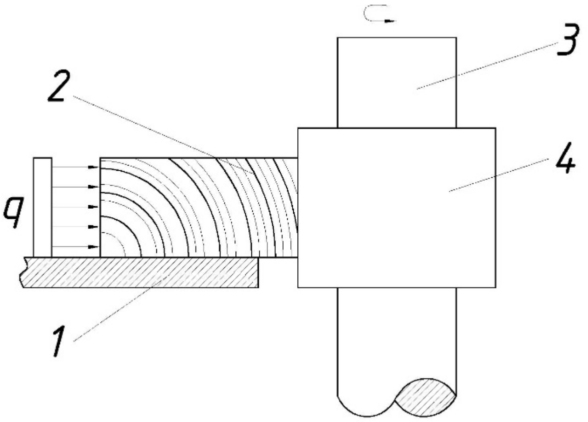

Figure 1: Principle scheme of a rotating steel lapping device: 1 – table of the spindle moulder; 2 – object for lapping (samples); 3 – spindle of the spindle moulder; 4 – working tool (cylindrical steel circlet).

The following variables were selected as variables during the experiment: linearly distributed force of pressing the samples to the axis of rotation of the milling spindle *q*, $kN.m^{-1}$; feeding speed of the samples *U*, $m.min^{-1}$; number of impacts to smooth the same surface of the samples, *n*.

The experiment was conducted using a 3-factor optimal B_3 type composite plan (Vuchkov at al., 1986). The three factors already mentioned are varied: $q = x_1$; $U = x_2$; $n = x_3$. The selected values of the factors as well as the intervals of their variation in the plan are shown in Table 1.

The following features are selected for the target functions: the final roughness of the lapped surfaces, determined by the parameter *Rm*, µm; the visual evaluation of the surfaces after lapping *Bb*, recorded by scoring. The values for the parameter *Rm* are calculated in accordance with the requirements of the standards (Kyuchukov at al., 2016). The following indicators have been taken into account in the determination of *Bb*: uniformity of smoothing; color changes due to burns during friction contact between processed surfaces and spindle. Scores, ranging from 0 to 5, are calculated by the method described in detail in other publications (Кавалов 1991, Kavalov at al., 2015). A score of "0" means surfaces in perfect condition and "5" means inappropriately poor condition requiring wastage of material after such smoothing. The lapping was consecutive to the four surrounding walls of each sample. The values of the indicators *Rm* and *Bb* for each sample were calculated as arithmetic mean from the measurements for its four surrounding walls. Non-lapped control sections were left to compare the effect of smoothing. The experimental data also sought a correlation between the two indicators.

RESULTS AND ANALISIES

The results of the three-factor experiment are presented in tables (Table 1 and 2) and analytically by the regression equations for *Rm* and *Bb*. In addition, Figures 2 to 5 provide some typical graphical solutions to these equations. Only those were selected, which give a clearer and objective view of the independent and combined influence of the variables on the degree and quality of the smoothing achieved. For roughness, the equation is:

$$Rm = 14.99–4.08x_1+4.08x_2-5.22x_3+5.07x_1^2+0.97x_2^2-0.03x_3^2+0.53x_1x_2-1.08x_2x_3- 0.58x_1x_3 \quad \textbf{(1)}$$

and for the visual evaluation of the surfaces after lapping:

$$Bb = 1.09-0.33x_1+0.39x_2-0.24x_3+0.04x_1^2+0.04x_2^2 +0.29x_3^2-0.18x_2x_3-0.08x_1x_3 \quad \textbf{(2)}$$

The check of both equations shows that the models are adequate (see Table 2). Their analysis shows that the relationships between the variable factors *q*, *U* and *n*, on the one hand, and the target functions *Rm* and *Bb*, on the other, are predominantly linear. The relatively equal values of the coefficients b_1, b_2, and b_3 mean that their effect on the lapping results is practically equivalent. Better parabolicity is observed in the functions of the type $Rm = f\ (x_1)$ and $Bb = f\ (x_3)$, for which the coefficients b_{11} and b_{33} are significantly higher than the others (respectively $b_{11} = 5.07$ and $b_{33} = 0.29$). In terms of the magnitudes of the dual interactions between plan factors, in most cases they are weak or moderately expressed for both *Rm* and *Bb*. Therefore, there is reason to ignore their impact on the results.

The established dependencies are logically explainable from a physics-mechanical point of view. It is normal to expect that by increasing the pressing force *q*, by reducing the feed speed *U* and by increasing the number of impacts *n*, an increased smoothing quality is achieved. This results in lower microgravity peaks, improved uniformity, and fiber removal.

Table 1: Values of the variable factors established during the experiment ("e") and calculated ("c") by plan B$_3$ for smoothing by lapping of steamed beech parts by rotating steel circlet

№	Variable factors			Target functions			
				Rm, µm		*Bb*, score	
	$x_1 = q$ kN.m^{-1}	$x_2 = U$ m.min^{-1}	$x_3 = n$ броя	„e"	„c"	„e"	„c"
1	9	12	3	15.6	14.64	1.1	1.03
2	3	12	3	22.3	22.9	1.8	1.83
3	9	4	3	7.6	7.58	0.6	0.59
4	3	4	3	19.1	17.94	1.4	1.41
5	9	12	1	27.4	28.38	2.0	2.01
6	3	12	1	34.5	34.34	2.5	2.52

№	Variable factors			Target functions			
				Rm, µm		*Bb*, score	
	$x_1 = q$ kN.m^{-1}	$x_2 = U$ m.min^{-1}	$x_3 = n$ броя	„*e*“	„*c*“	„*e*“	„*c*“
7	9	4	1	17.8	17.02	0.9	0.88
8	3	4	1	24.3	25.08	1.3	1.39
9	9	8	2	15.2	15.97	0.7	0.80
10	3	8	2	24.2	24.13	1.6	1.46
11	6	12	2	20.5	20.03	1.5	1.52
12	6	4	2	10.7	11.87	0.8	0.74
13	6	8	3	8.2	9.73	1.1	1.14
14	6	8	1	21.0	20.17	1.7	1.62
15	6	8	2	16.4	14.99	1.0	1.09

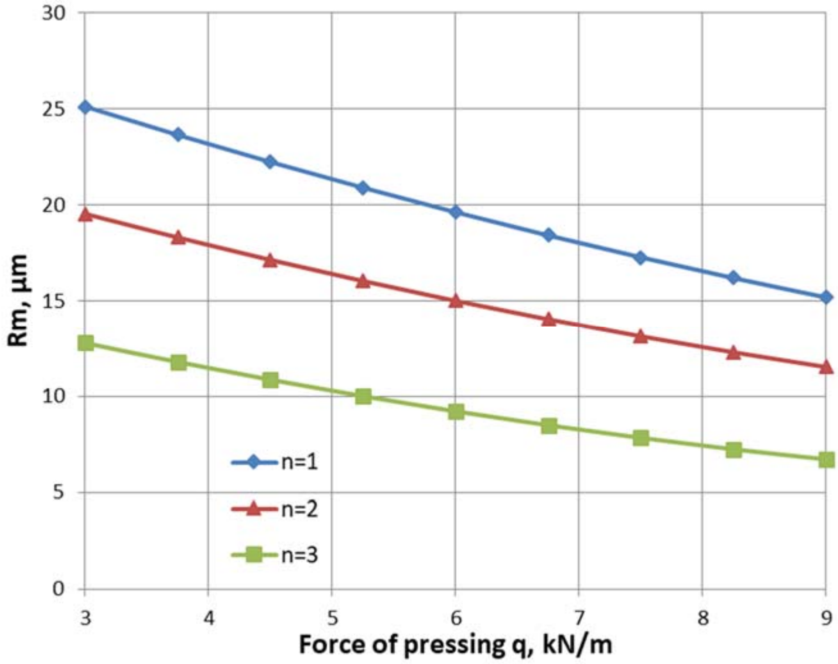

Figure 2: Effect of the pressing force *q* and the number of impacts *n* on the final roughness *Rm* at the feed speed *U* = 8 m.min^{-1}

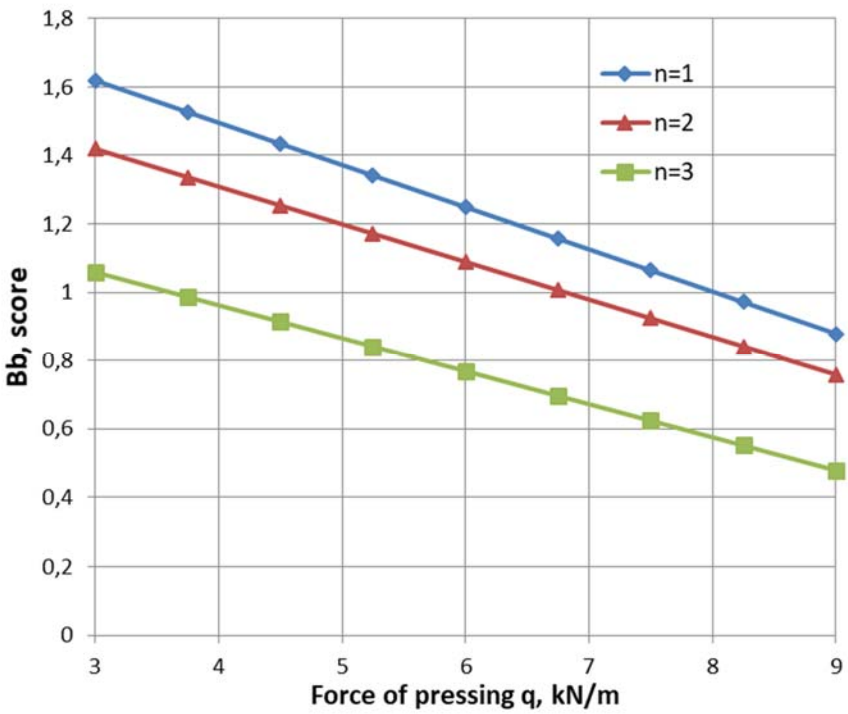

Figure 3: Effect of the pressing force *q* and the number of impacts *n* on the visual score *Bb* at feed speed *U* = 8 m.min^{-1}

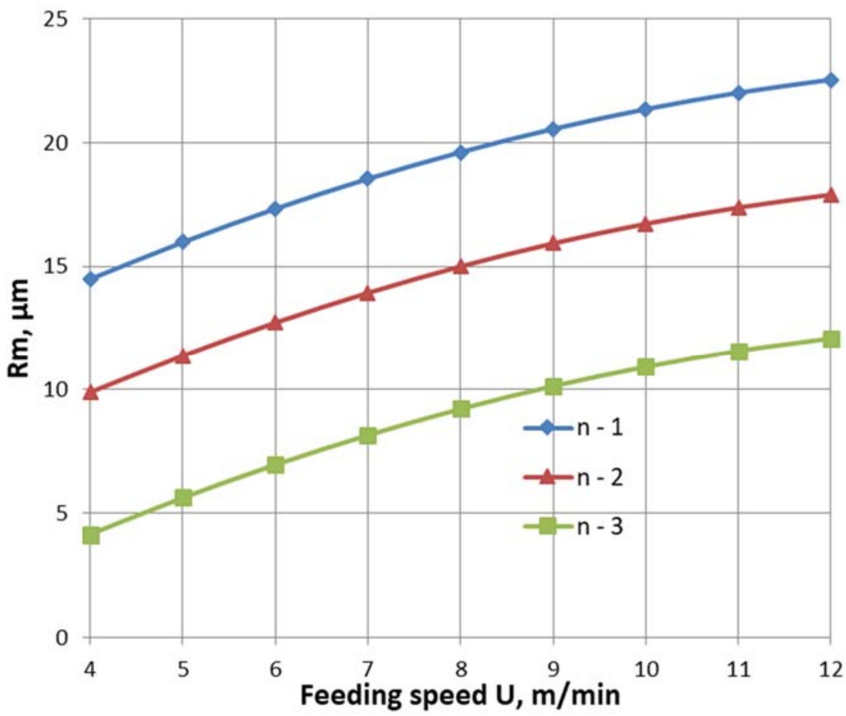

Figure 4: Effect of the feed speed *U* and the number of impacts *n* on the final roughness *Rm* at pressing force *q* = 6 kN.m^{-1}

Evaluated from the point of view of the possibilities for practical application of the researched method, the achieved results show that there are real preconditions for their future production implementation in technological processes for formation of film coatings.

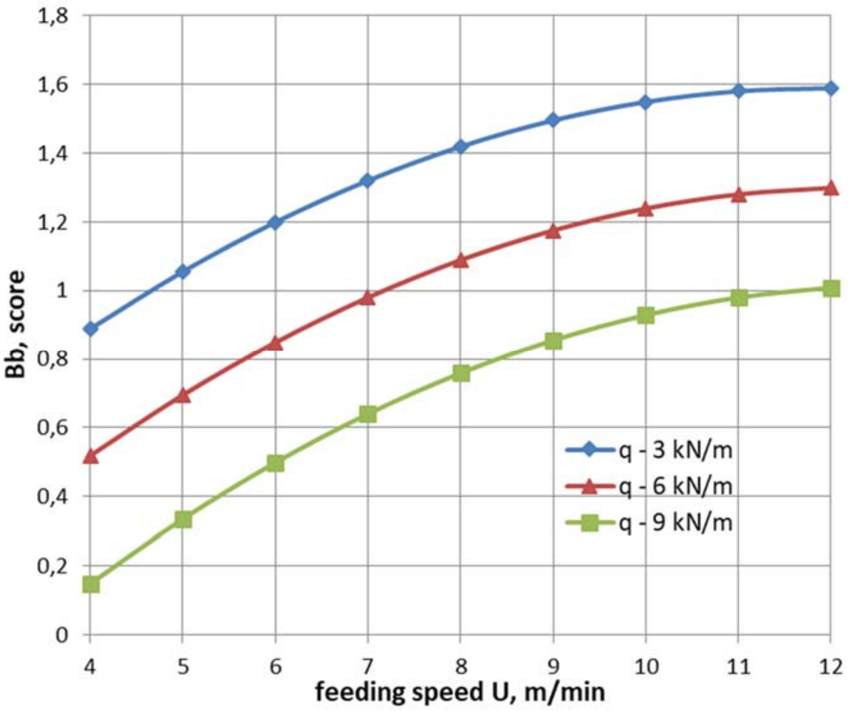

Figure 5: Effect of feed speed *U* and pressing force *q* on the visual score *Bb* in the number of impacts *n* = 2

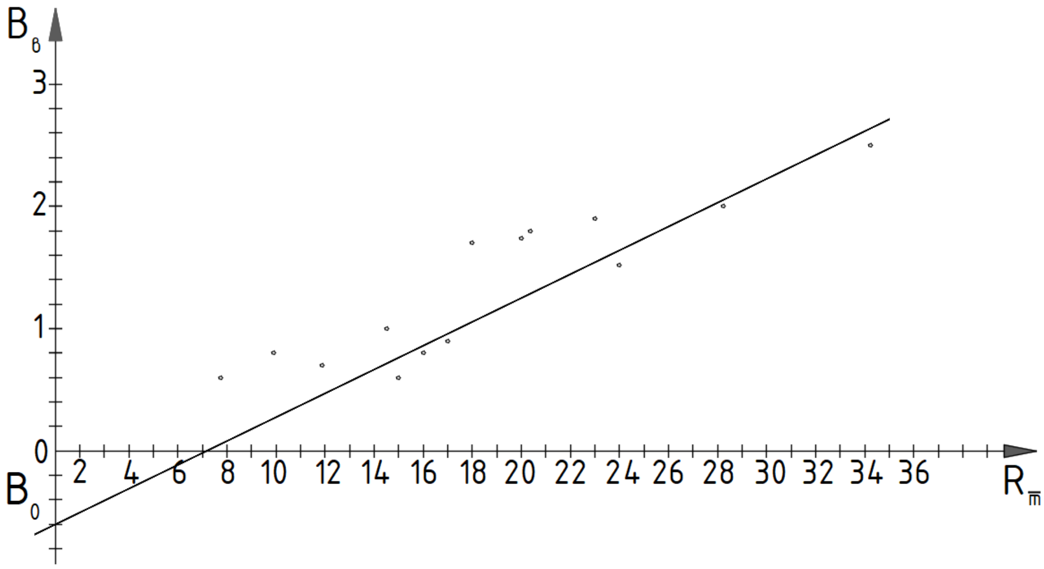

Figure 6: Graphical view of the correlation between the target functions *Rm* и *Вв*

When looking for optimal variants of technological modes for smoothing wood surfaces before varnishing, it is worth considering the following circumstances:

- In order to minimize technological difficulties, it is recommended to lapping once (*n*=1);
- When it is necessary to increase the productivity, it is possible to choose a higher feed speed, for example 10 $m.min^{-1}$, without the risk of deterioration of the quality of the smoothed surfaces;
- Expected less favorable results of rubbing with increased speed *U* can

be avoided by a moderate increase in pressing force *q*. However, the increase must not lead to darkening or partial scorching of the surfaces due to the thermal effect of the increased friction.

Table 2: Characteristic of the regression model for plan B3 according to the data in Table 1

Type of coefficient	Target functions. Coefficient values for:		Additional data for the regression model
	***Rm*, μm**	***Bb*, score**	
b_0	14.99	1.09	F_{Rm} *tab.*= 4.77 F_{Rm} *calc.*= 2.57 F_{Bb} *tab.*= 4.15 F_{Bb} *calc.*= 2.44 The models are adequate. Multiple regression coefficients: R_{Rm}=0.98; R_{Bb}=0.98
b_1	-4.08	-0.33	
b_2	4.08	0.39	
b_3	-5.22	-0.24	
b_{11}	5.07	0.04	
b_{22}	0.97	0.04	
b_{33}	-0.03	0.29	
b_{12}	0.53	0.00	
b_{23}	-1.08	-0.18	
b_{13}	-0.58	-0.08	

The analysis of the graphics in Figures 2 to 5, as well as the combination of selected solutions of the regression equations for *Rm* and *Bb*, made it possible to select and propose the following two variants of the optimal technological modes for smoothing by lapping:

1. Pressing force q = 9 kN.m^{-1}; feed speed U = 8 m.min^{-1}; single treatment (n = 1). Under these conditions, high-quality smoothing is expected by *Rm* ≈15 μm and *Bb*= 0.9.

2. Pressing force q = 10 kN.m^{-1}; feed speed U = 10 m.min^{-1}; single treatment (n = 1). The same smoothing quality is achieved for this mode variant, i.e. *Rm* ≈15 μm and *Bb* = 0.9.

It is necessary to clarify that according to the requirements approved by practice, the smoothing of wood surfaces is considered to be performed as high quality, when *Rm* ≤15 μm and *Bb* ≤1. Another side of the analysis of the results of the lapping with a rotating steel circlet shows that there is a well-defined correlation between the two estimation parameters for the degree of smoothing - *Rm* and *Bb*. The additional calculation showed that the correlation coefficient between these two values $r_{Rm/Bb}$ is 0,84. Visibility of the dependence *Rm* = *f* (*Bb*) can be obtained from the graph given in Fig. 6. The regression equations between these two parameters are of the form:

$$Rm = 11{,}8.B\text{в} + 4{,}7,\ \mu m\ (\sigma = \pm 3.3\mu m) \quad (3)$$

$$B\text{в} = 0{,}085.Rm - 0{,}4\ (\sigma = \pm 0.21) \quad (4)$$

The practical benefit of deriving these dependencies is that with available experimental data for one parameter with a high degree of reliability, appropriate values can be determined for the other without the need for additional measurements. In conclusion, it should be added that the experimentally studied method of smoothing by lapping can be implemented in other variants that are suitable for practical use. Their research is the subject of further developments.

CONCLUSION

The results of the experimental studies give reason to do the following summarized conclusions:

1. Lapping for smoothing before varnishing solid wood details is actually applicable in production conditions.
2. Specific regimes for its implementation are proposed, the production

of which does not require complicated and expensive technological preparation.

3. It is possible to further improve the proposed method in order to find the most suitable conditions for its more efficient use.

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