Determination of Surface Roughness Based on the Sanding Parameters of Oriental Beech Wood

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This study demonstrated the strength of a theoretical model founded on the Box-Behnken experimental design method to determine the surface roughness (R_a parameter) of solid Oriental beech (*Fagus orientalis* Lipsky) wood. The working parameters (sanding belt grit size of 60 to 100, feeding speed of 4 m/min to 10 m/min, and sanding cutting depth of 0.1 mm to 0.3 mm) of a wide belt sanding machine were determined. The R_a of the samples was experimentally described so that the experimental results were also remodeled with the Box-Behnken method to find the optimum parameters for the lowest R_a. An adjusted correlation factor of 93.6% for the R_a confirmed the compatibility between the experimental and theoretical findings. The high correlation (strength) allowed for a more detailed discussion of the effect of the working parameters on the R_a. The theoretical approach showed that the grit size factor had the largest effect on the R_a compared with the other factors. The optimum parameters were found to be a grit size of 100, feed speed of 4 m/min, and sanding depth of 0.1 mm for a minimum R_a for Oriental beech wood. The experimental data supported these parameters.

Keywords: Surface roughness; Box-Behnken design; Grit size; Feed speed; Sanding thickness

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INTRODUCTION

Surface roughness (R_a parameter) in wood materials is one of the most important factors that affects the finishing operations with regards to the bonding quality, especially the painting characteristics. A material surface should be as smooth as possible before starting finishing operations. It is not possible to obtain a completely smooth surface, even in wood materials processed with proper techniques, by reason of cell size. However, the roughness can be reduced before finishing operations are conducted. The factors affecting the surface smoothness of a wood material may be summed under three groups, including the properties of the wood material, cutters, and machines (Kilic *et al.* 2006; Malkoçoğlu 2007; Aslan *et al.* 2008; Magoss 2008).

In much more detail, there are several quantity factors affecting the surface roughness (arithmetic average of surface irregularities with regard to a mean line). The factors can largely be classified into four main groups: (I) the machining parameters including the feed rate, cutting speed, and depth of cut; (II) the cutting tool parameters as regards the wear, geometry, material, and coating of tools used; (III) the machining and machine tool conditions regarding the dry or wet turning, cutting fluid type, fluid applications, machine tool rigidity, and vibration of chatter; and (IV) the workpiece material properties (hardness, microstructure, grain size, and inclusions) (Ratnam 2017).

Researchers have studied such properties in detail and searched for ways to obtain smoother surfaces. Taylor *et al.* (1999) and Fujiwara *et al.* (2001) found that high quality wood material surfaces may be obtained if the proper feeding speed and grit size are determined in the sanding process (Tan *et al*. 2012), which established that the grit size and feed speed are effective at reducing the R_a.

Budakçı *et al.* (2011) reported that a quality surface is also dependent on the chip thickness and cutting velocity, as well as the rake angle. Örs and Baykan (1999) found that when the number of cutters and grit size in the sanding process are higher, then the values of the R_a are lower. According to the studies mentioned above, the sanding operation, which depends on the textural features, anatomical or cell structure, annual ring differentiation, ratio between early wood and latewood, moisture, and density, also plays an important role in understanding how or why the surface quality changes during processing (Ratnasingam and Scholz 2006; Hiziroglu *et al.* 2013; Hazir *et al.* 2017). Similarly, the research shows a preference for the optimum sanding operation parameters (including the grit size, feed speed, and sanding depth) for a wide belt sanding machine with respect to the wood properties, such as the anisotropic nature and heterogeneous texture (Saloni *et al.* 2010).

Additionally, different researchers have indicated that tangential cutting results in a softer surface than radial cutting, but the interaction among the cutting destination and sort of cutter is not significant (Örs and Baykan 1999; Örs and Gürleyen 2002; Efe and Gürleyen 2003; Söğütlü 2005; Malkoçoğlu 2007). Studies in which the R_a was optimized with an experimental design method (response surface design) have frequently been conducted in recent years and mostly in different areas (Kant and Sangwan 2014; Luo *et al.* 2014; López *et al.* 2016; Nguyen and Hsu 2016; Sofuoglu 2017).

Scientists can also classify attractive properties, such as changes, permanent variances, and conformity for locking, with the assistance of statistical analyses and response surface designs (Box *et al.* 1978). In this regard, the classic quadratic designs are sorted into two main groups, including the Box-Wilson central composite and Box-Behnken designs. Classic models have allowed the researchers to determine the optimum locations in the industry, technology, and engineering application fields for several years (Box and Behnken 1960; Ayodele and Cheng 2015; Ba-Abbad *et al.* 2015; Shahri and Niazi 2015; Montgomery 2017). The Box-Behnken design is a free (rotatable) quadratic design because of the lack of a buried or fractional factorial design. Therefore, the Box-Behnken design combined with rarer cure alternatives limits the ability for orthogonal locking in proportion with the central composite designs. Additionally, the Box-Behnken design shows benefits in rarer cure alternatives in the literature. In the present work, the preparation conditions, including the grit size, feed speed, and sanding depth, were determined with the Box-Behnken design to optimize the R_a of oriental beech materials.

EXPERIMENTAL

Materials

Oriental beech wood was selected because it is frequently used in the furniture industry in Turkey, easily accessible, has a reasonable price, and the processing methods are familiar. A total of 15 Oriental beech air-dried samples for 15 main groups (totally 225 samples), measuring 18 mm × 110 mm × 350 mm, were designed according to TS 2470 (2005). The annual rings were on the surfaces vertically. The wood was a high grade, finely fibrous, knotless, crack-free, and had no differences in the color or density. Subsequently, they were stored at 20 °C ± 2 °C and 65% ± 5% relative humidity in a conditioning cabinet until they reached a constant weight. The experimental materials (air-dry density of

0.69±0.03 and moisture content levels of 9±1 %) were sanded with a wide belt sanding machine (Version 1100 Melkuç Machine Company, Ankara, Turkey). The machine and sanding belt properties are shown in Table 1.

Table 1. Machine and Sanding Characteristics

Machine Kombi-1100	Sanding Belt TX-146
Rotation of Drums: 2000 rpm Cutting Speed: 16.75 m/s Feed Speed: 4 m/dk to 16 m/dk with Inverter Machine Working Width: 1080 mm Total Power: 17.6 kw	Grain Type: Aluminum Oxide Size (mm):1100*1900 Backing Material: X-wt.% Poly/Cotton Coating State: Medium Coat Bonding: Resin Over Resin Usage State: First Use

Surface Roughness Test

The R_a of the samples was defined according to ISO 4287 (1997) using a stylus profilometer (TIME TR200, Time Group Inc., Beijing City, China). The measurements were made parallel to the fibers at five different points on each sample. The mean line between the profile valleys and ridges was the average R_a value in micrometers (Fig. 1).

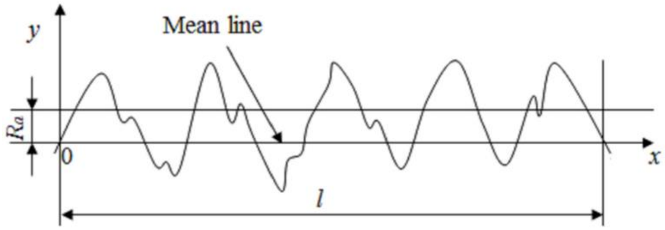

Fig. 1. Graphical representation of the R_a (Nguyen and Hsu 2016)

Experimental Design and Statistical Method

The three factor Box-Behnken experimental design method was preferred in this study. The Box-Behnken design is an independent quadratic model. It does not include a full or partial factorial design. The testing points were located on the mid points of the edges and on the center. These models are rotatable and need three levels for each factor. The center of the design has a limited capability for orthogonal blocking compared with composite designs. When the same number of factors exist, this design is more economical because it includes a lower number of points compared with central composite designs. The three factor Box-Behnken design necessitates 15 tests and the four-factor design necessitates 27 tests (Winer *et al.* 1991; Myers *et al.* 2016).

In the Box-Behnken experimental design, each experimental factor must identify the minimum or lower level (-1), central or medium level (0), and higher or maximum level (+1). The independent variables of this study were the grit size, feed speed, and sanding depth, while the dependent variable was the R_a. The specified experimental points are given in Table 2. The experiments were repeated in triplicate to represent the mid points and were repeated to estimate the errors.

Table 2. Experimental Points Used in the Box-Behnken Experimental Design Method

Group Number (each one includes 15 sample)	Grit Size (grit)	Feed Speed (m/min)	Sanding Depth (mm)
1	80	4	0.10
2	60	7	0.30
3	100	7	0.10
4	100	10	0.20
5	60	7	0.10
6	60	10	0.20
7	80	10	0.30
8	100	7	0.30
9	80	4	0.30
10	80	7	0.20
11	80	10	0.10
12	80	7	0.20
13	60	4	0.20
14	100	4	0.20
15	80	7	0.20

The following response surface function was used to correlate the R_a (Y) with the independent variables (X_1, X_2, and X_3) (Eq. 1):

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{23} X_3^2 \tag{1}$$

where Y is the R_a, b_0 is the value taken by Y in case the effect of all of the independent variables is zero, X_1, X_2, and X_3 are the grit size, feed speed, and sanding depth, respectively, b_1, b_2, and b_3 are linear coefficients, b_{12}, b_{13}, and b_{23} are interaction coefficients among the independent variables, and b_{11}, b_{22}, and b_{33} are second degree coefficients.

The MINITAB statistical software program (Minitab Inc., State College, PA, USA) was used to perform the experimental design, determine the coefficients, perform the data analysis, and generate the graphs. The validity checks of the obtained model were made by comparing the experimental data and estimated values.

RESULTS AND DISCUSSION

The R_a values obtained as a result of the Box-Benkhen experimental design and experiments are given in Table 2. The values given in the chart indicate both the 3-level structure used in the surface response method and the experimental values corresponding to these levels. The highest R_a value (12.87 µm) was obtained with a 60-grit sanding belt size, 10-m/min feeding speed, and 0.20-mm sanding depth. The lowest R_a (7.05 µm) was acquired with a 100-grit sanding belt, 4-m/min feeding speed, and 0.2-mm sanding depth (Table 3).

The effects of the feed speed and sanding depth parameters on the R_a were tested with two different models (linear and square) and an analysis of variance (ANOVA), and the results are shown in Table 4. The independent effects of the parameters were seen in the linear model, while the effectiveness of the squares of the parameters was determined in the square model. Accordingly, the correlation of the grit size and speed parameters with the R_a was found to be important for the linear model ($P < 0.050$). The correlation of the grit size square with the R_a was found to be important for the square model ($P < 0.050$). It was concluded based on the results that the grit size had the largest effect on the R_a.

Table 3. Experimental Design and Results

Group Number	Grit Size of Sanding Belt (grit)	Feed Speed (m/min)	Sanding Depth (mm)	R_a Experiment Value (Average of each group)
1	80	4	0.10	9.28
2	60	7	0.30	11.33
3	100	7	0.10	7.84
4	100	10	0.20	8.11
5	60	7	0.10	11.27
6	60	10	0.20	12.87
7	80	10	0.30	11.14
8	100	7	0.30	8.47
9	80	4	0.30	10.81
10	80	7	0.20	10.30
11	80	10	0.10	10.75
12	80	7	0.20	11.44
13	60	4	0.20	10.35
14	100	4	0.20	7.05
15	80	7	0.20	10.01

Table 4. Results of the ANOVA of the R_a

Source	Degree of Freedom	Adjusted Sum of Squares	Adjusted Mean Squares	F-Value	P-Value
Model	9	34.09	3.79	8.96	0.013
Linear Model	3	30.26	10.09	23.86	0.002
Grit Size	1	25.78	25.78	60.99	0.001
Feed Speed	1	3.63	3.63	8.58	0.033
Sanding Depth	1	0.86	0.83	2.03	0.214
Square Model	3	2.89	0.96	2.28	0.197
Grit Size * Grit Size	1	2.85	2.85	6.74	0.048
Feed Speed * Feed Speed	1	0.04	0.04	0.1	0.763
Sanding Depth * Sanding Depth	1	0.00	0.00	0.00	0.947
Error	5	2.11	0.42		
Lack-of-Fit	3	0.97	0.32	0.56	0.69
Pure Error	2	1.15	0.57	-	-
Total	14	36.20	-	-	-
R^2: 94.16%					

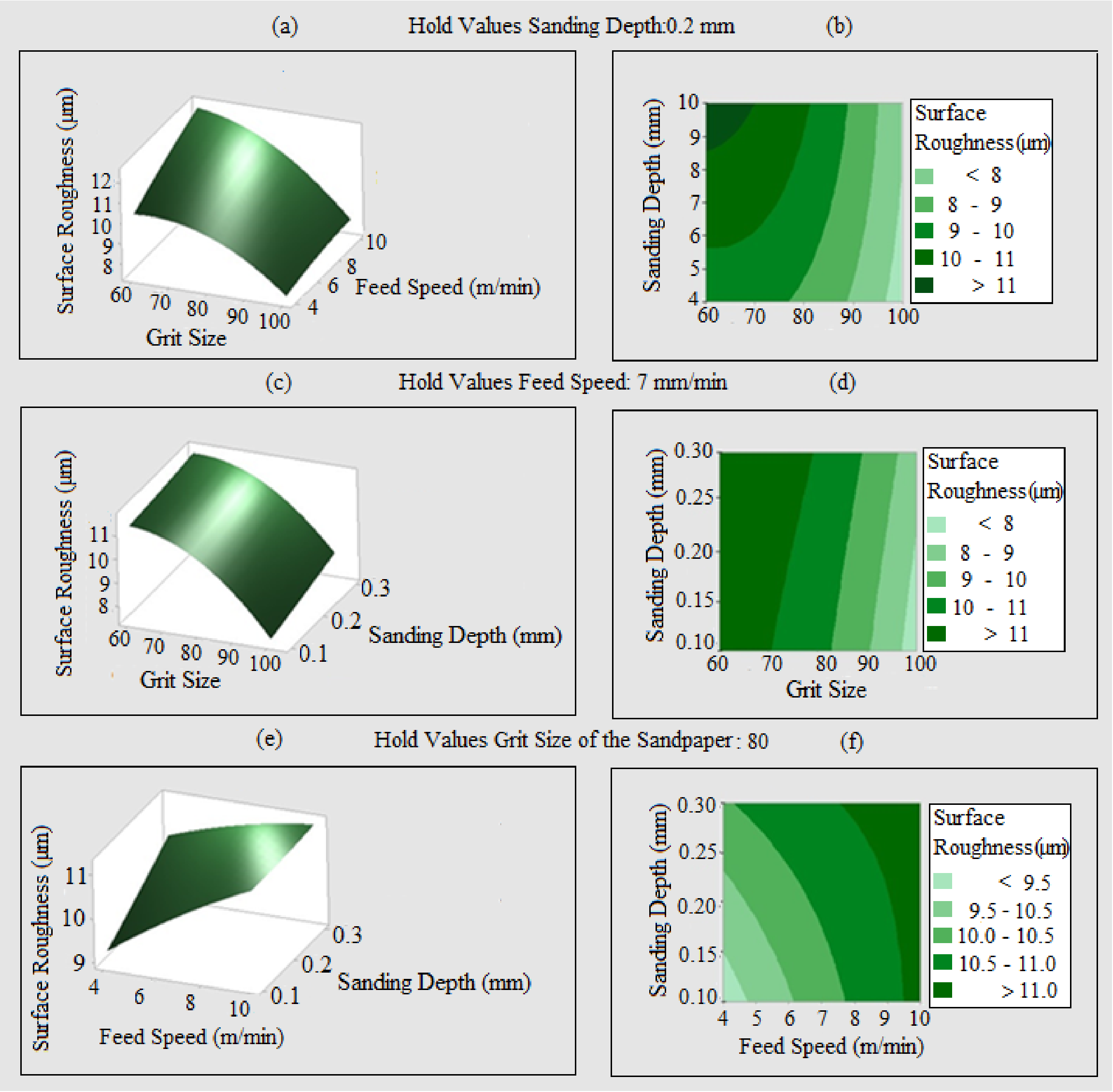

Fig. 2. Surface plots and counter plot charts of the parameters

The combined effect of the three parameters on the R_a was interpreted with the surface plots and counter plot graphs, which are given in Fig. 2. The sanding depth was kept at 0.2 mm in Figs. 2a (surface plot) and 2b (counter plot). According to Fig. 2a, when the grit size increased, the R_a slightly increased, even though the feed speed increased. If the grit size increased and the feed speed decreased, the R_a was reduced. The same correlation was seen in the counter plot graph (Fig. 2b), where a 100-grit sanding belt size and feed speed below 7.5 m/min were required to obtain a R_a below 8 µm. The feed speed was kept at 0.7 m/min in Figs. 2c (surface plot) and 2d (counter plot). Figure 2c shows that the R_a was reduced when the grit size increased and the sanding depth decreased. The R_a increased slightly when the grit size increased, even though the sanding depth increased. Figure 2d shows that a 100-grit sanding belt size and sanding depth below 0.21 mm was required to obtain an R_a value below 8 µm. According to Fig. 2e (surface plot) and 2f (counter plot), the grit size was kept at 80. The R_a was reduced when the feed speed and sanding depth decreased. The R_a increased slightly when the feed speed increased, even though the sanding depth increased (Fig. 2e). According to the counter plot graph (Fig. 2f) a sanding depth below 0.21 mm and feed speed below 5 m/min were required for an R_a value below 8 µm.

The mathematical method obtained from the experimental data analyzed with the surface response method is given below (Eq. 2):

$$Ra = -2.63 + 0.2960\,\mathit{Grit\ size} + 1.069\,\mathit{Feed\ speed} + 3.4\,\mathit{Sanding\ depth} - 0.002196\,\mathit{Grit\ size} \times \mathit{Grit\ size} - 0.0120\,\mathit{Feed\ speed} \times \mathit{Feed\ speed} + 2.4\,\mathit{Sanding\ depth} \times \mathit{Sanding\ depth} - 0.00609\,\mathit{Grit\ size} \times \mathit{Feed\ speed} + 0.070\,\mathit{Grit\ size} \times \mathit{Sanding\ depth} - 0.95\,\mathit{Feed\ speed} \times \mathit{Sanding\ depth} \tag{2}$$

The mathematical model founded on the experimental measurement results was used to determine the lowest R_a, which is seen in Fig. 3. It was apparent from the graphs that the lowest R_a was 6.765 when the sanding parameters were a 100-grit sanding belt size, 4-m/min feed speed, and 0.1-mm sanding depth.

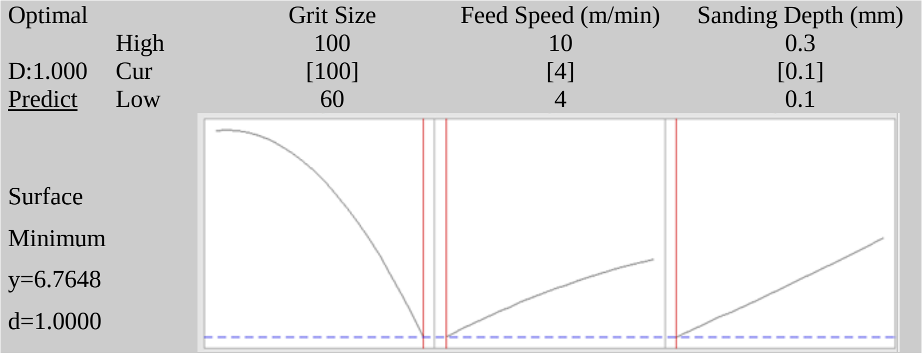

Fig. 3. Optimum parameters for the minimum R_a

Additionally, the correlation between the experimental results and estimations can be seen in Fig. 4.

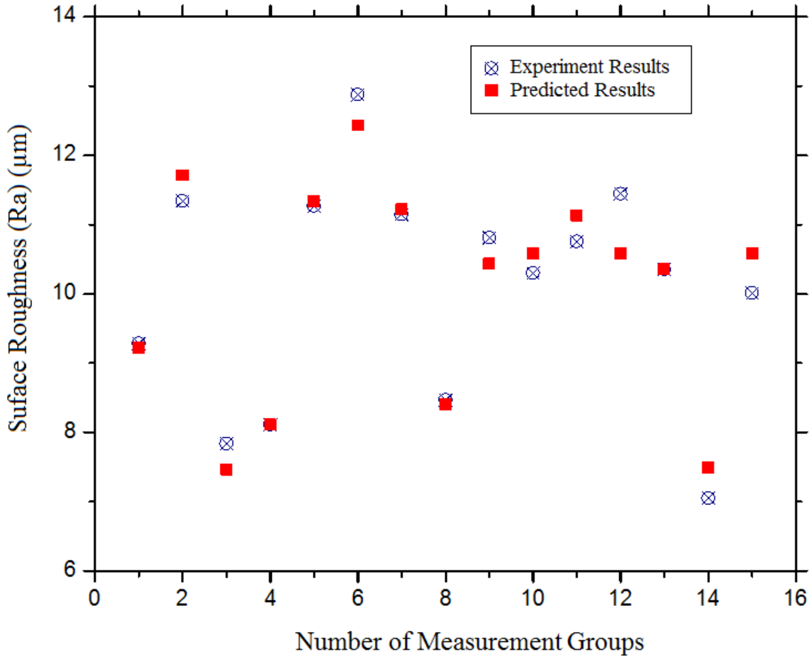

Fig. 4. Test results and estimated R_a values

It was determined from Fig. 4 that the R^2 was 0.9410 and the adjusted R^2 was 0.9360. This indicates there was good compatibility between the computed theoretical values and experimental measurement results. The values obtained with the R_a estimation model explained 93.6% of the experimental variation. Moreover, the compatibility of the R^2 and adjusted R^2 showed that the model functions chosen during this study were suitable for the determination of R_a parameters for Oriental beech wood.

CONCLUSIONS

The surface roughness value resulting from the sanding of solid beech surfaces was found to be correlated with feed speed, sanding depth quantity and the grit size, and successfully remodeled with regard to the Box Benkhen experimental design method. According to regression between model results and experiment values for the working parameters on the surface roughness, the adjusted correlation factor was computed to be 93.6%, presenting the perfect compatibility, operation and superiority of the theoretical model used in this work. Accordingly;

1. It was found that the factors of feed speed and the grit size were statistically important and significant regarding the surface roughness value, while the sanding depth parameter was not statistically significant. In the square model, only the grit size was found to be statistically important and significant. This was attributed to the fact that the most effective factor on surface roughness value is the grit size depending on the low surface roughness. In other words, the higher the grit size, the lower the surface roughness.

2. To the best of our knowledge, there are several studies on the working parameters of the sanding machine in regards to feed speed (Magoss 2008); feed speed and the grit size (Taylor *et al.* 1999; Fujiwara *et al.* 2001); grit size and feed speed (Tan *et al.* 2012); and grit size, feed rate, depth of cut, and cutting speed (Hazir *et al.* 2017). In these studies, the researchers produced rather smoother surface for wood production. The present work endeavored to optimize the working parameters such as feed speed, the grit size and sanding depth for the minimum surface roughness of beech wood.

3. According to the results deduced from the model, the combination of 100 grit sanding belt, 4 m/min feed speed, and 0.1 sanding depth was corrected by both the experimental evidence and theoretical results for the lowest surface roughness on solid beech surfaces. Consequently, the present results confirm that effective optimization can be achieved by means of a Box Benkhen experimental design model using a low number of experimental measurements points.

4. The theoretical model correctly selected for the specific work enables the researchers to easily and economically decide the optimum working parameters for the smoothest surface roughness.

REFERENCES CITED

Aslan, S., Coşkun, H., and Kılıç, M. (2008). "The effect of the cutting direction, number of blades and grain size of the abrasives on surface roughness of Taurus cedar (*Cedrus libani* A. Rich.) woods," *Build. Environ.* 43(5), 696-701. DOI: 10.1016/j.buildenv.2007.01.048

Ayodele, B. V., and Cheng, C. K. (2015). "Modelling and optimization of syngas production from methane dry reforming over ceria-supported cobalt catalyst using artificial neural networks and Box–Behnken design," *J. Ind. Eng. Chem.* 32, 246-258. DOI: 10.1016/j.jiec.2015.08.021

Ba-Abbad, M. M., Chai, P. V., Takriff, M. S., Benamor, A., and Mohammad, A. W. (2015). "Optimization of nickel oxide nanoparticle synthesis through the sol–gel method using Box–Behnken design," *Mater. Design* 86, 948-956. DOI: 10.1016/j.matdes.2015.07.176

Box, G. E. P., and Behnken, D. W. (1960). "Some new three level designs for the study of quantitative variables," *Technometrics* 2(4), 455-475. DOI: 10.2307/1266454

Box, G. E. P., Hunter, W. G., and Hunter, J. S. (1978). *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley and Sons, Hoboken, NJ.

Budakçı, M., İlçe, A. C., Korkut, D. S., and Gürleyen, T. (2011). "Evaluating the surface roughness of heat-treated wood cut with different circular saws," *BioResources* 6(4), 4247-4258. DOI: 10.15376/biores.6.4.4247-4258

Efe, H., and Gürleyen, L. (2003). "The effects of cutting direction, number of cutter and the rotation value on surface smoothness for some wood species," *Journal of Industrial Arts Education* 11(12), 34-35.

Fujiwara, Y., Fujii, Y., Sawada, Y., and Okumura, S. (2001). "Development of a parameter to reflect the roughness of a wood surface that corresponds to tactile roughness," *Eur. J. Wood Wood Prod.* 59(5), 351-355. DOI: 10.1007/s001070000161

Hazir, E., Hüseyin Koc, K., and Hiziroglu, S. (2017). "Optimization of sanding parameters using response surface methodology," *Maderas-Cienc. Tecnol.* 19(4), 407-416. DOI: 10.4067/S0718-221X2017005000101

Hiziroglu, S., Zhong, Z. W., and Tan, H. L. (2013). "Measurement of bonding strength of pine, kapur and meranti wood species as function of their surface quality," *Measurement* 46(9), 3198-3201. DOI: 10.1016/j.measurement.2013.05.005

ISO 4287 (1997). "Geometrical product specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters," International Organization for Standardization, Geneva, Switzerland.

Kant, G., and Sangwan, K. S. (2014). "Prediction and optimization of machining parameters for minimizing power consumption and surface roughness in machining," *J. Clean. Prod.* 83, 151-164. DOI: 10.1016/j.jclepro.2014.07.073

Kilic, M., Hiziroglu, S., and Burdurlu, E. (2006). "Effect of machining on surface roughness of wood," *Build. Environ.* 41(8), 1074-1078. DOI: 10.1016/j.buildenv.2005.05.008

López, A., Aisa, J., Martinez, A., and Mercado, D. (2016). "Injection moulding parameters influence on weight quality of complex parts by means of DOE application: Case study," *Measurement* 90, 349-356. DOI: 10.1016/j.measurement.2016.04.072

Luo, B., Li, L., Liu, H., Xu, M., and Xing, F. (2014). "Analysis of sanding parameters, sanding force, normal force, power consumption, and surface roughness in sanding wood-based panels," *BioResources* 9(4), 7494-7503. DOI: 10.15376/biores.9.4.7494-7503

Magoss, E. (2008). "General regularities of wood surface roughness," *Acta Silvatica et Lignaria Hungarica* 4, 81-93.

Malkoçoğlu, A. (2007). "Machining properties and surface roughness of various wood species planed in different conditions," *Build. Environ.* 42(7), 2562-2567. DOI: 10.1016/j.buildenv.2006.08.028

Montgomery, D. C. (2017). *Design and Analysis of Experiments*, 9th Ed., John Wiley and Sons, Hoboken, NJ.

Myers, R. H., Montgomery, D. C., and Anderson-Cook, C. M. (2016). *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, 4th Ed., John Wiley and Sons, Hoboken, NJ.

Nguyen, H.-T., and Hsu, Q.-C. (2016). "Surface roughness analysis in the hard milling of JIS SKD61 alloy steel," *Appl. Sci.-Basel* 6(6), 172. DOI: 10.3390/app6060172

Örs, Y., and Baykan, I. (1999). "The effects of planning and sanding on surface roughness for solid wood material," *Turk. J. Agric. For.* 23(3), 577-582.

Örs, Y., and Gürleyen, L. (2002). "Effect of the cutting direction, number of knives and cutter species to surface smoothness on wood material for planning," *Journal of Polytechnic of Gazi University* 5(4), 335–339.

Ratnam, M.M. (2017). "Factors affecting surface roughness in finish turning reference module in materials science and materials engineering," *Comprehensive Materials Finishing* (1), 1-25. DOI: 10.1016/B978-0-12-803581-8.09147-5

Ratnasingam, J., and Scholz, F. (2006). "Optimal surface roughness for high-quality finish on rubberwood (*Hevea brasiliensis*)," *Holz. Roh. Werkst.* 64(4), 343-345. DOI: 10.1007/s00107-005-0068-6

Saloni, D. E., Lemaster, R. L., and Jackson, S. D. (2010). "Process monitoring evaluation and implementation for the wood abrasive machining process," *Sensors-Basel* 10(11), 10401-10412. DOI: 10.3390/s101110401

Shahri, F. B., and Niazi, A. (2015). "Synthesis of modified maghemite nanoparticles and its application for removal of acridine orange from aqueous solutions by using Box-Behnken design," *J. Magn. Magn. Mater.* 396, 318-326. DOI: 10.1016/j.jmmm.2015.08.054

Sofuoglu, S. D. (2017). "Determination of optimal machining parameters of massive wooden edge glued panels which is made of Scots pine (*Pinus sylvestris* L.) using Taguchi design method," *Eur. J. Wood Wood Prod.* 75(1), 33-42. DOI: 10.1007/s00107-016-1028-z

Söğütlü, C. (2005). "The effect of some factors on surface roughness of sanded wood material," *Journal of Polytechnic* 8(4), 345–350.

Tan, P. L., Sharif, S., and Sudin, I. (2012). "Roughness models for sanded wood surfaces," *Wood Sci. Technol.* 46(1-3), 129-142. DOI: 10.1007/s00226-010-0382-y

Taylor, J. B., Carrano, A. L., and Lemaster, R. L. (1999). "Quantification of process parameters in a wood sanding operation," *Forest Prod. J.* 49(5), 41-46.
TS 2470 (2005). "Wood - Sampling methods and general requirements for physical and mechanical tests," Turkish Standards Institution, Ankara, Turkey.
Winer, B. J., Brown, D. R., and Michels, K. M. (1991). *Statistical Principles in Experimental Design*, McGraw-Hill, New York, NY.

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