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A Study on the Beech Wood Machining Parameters Optimization Using Response Surface Methodology

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Abstract: The surface quality of wooden products is of great importance to production industries. The best surface quality requires a thorough understanding of the cutting parameters' effects on the wooden material. In this paper, response surface methodology, which is one of the conventional statistical methods in experiment design, has been used to design experiments and investigate the effect of different machining parameters as feed rate, spindle speed, step over, and depth of cut on surface quality of the beech wood. The mathematical model of the examined parameters and the surface roughness have also been obtained by the method. Finally, the optimal machining parameters have been obtained to achieve the best quality of the machined surface, which reduced the surface roughness up to 4.2 (μm). Each of the machining parameters has a considerable effect on surface quality, although it is noted that the feed rate has the greatest effect.

Keywords: optimization; response surface method; surface roughness; machining parameters

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1. Introduction

In recent years, the wood industry has gained significant attention for its applications in various industries and because the wood and its products are very important in industrial production. The surface roughness, as the main parameter of surface quality, is among the requirements for quality production. The examination of the methods conducive to achieve the optimal cutting parameters for the minimum surface roughness of wooden products is one of the vital research issues that fill the gap existing in the literature in this respect.

Fujiwara et al. [1] have investigated the surface roughness of Japanese oak and beech that were polished with different sandpapers, and after paying attention to the distribution of the respective area the peaks of the roughness profile were checked. Usta et al. [2] have studied the effect of the number of grater knife blades, feed speed and depth of cut on the surface roughness of Acacia locust and European oak in the planning process. The samples have been tested with two and four blades, feeding speed of 5 and 9 (m/min) and cutting depth of 1, 2 and 4 (mm), respectively. It should be noted that under the same conditions, Acacia Locust has a smoother surface than European oak. They found that the surface roughness decreases by reducing the feed speed and depth of cut and increasing the number of grater blades. The lowest surface roughness in the experiment with the highest number of grater blades (4 blades), feed rate of 5 m per minute and cutting depth of 1 (mm) is achieved. Hernández et al. [3] have investigated the effect of cutting width and height on the surface quality of black spruce timber in the process of turning the trunk into lumber. So that the spindle speed and feed rate are kept constant, surface roughness tests have been performed in two conditions of summer and winter temperature and different cutting width and height. Finally, they obtained the suitable surface quality in summer temperature where the width and height of cut of the black spruce was less. Kilic et al. [4] have evaluated the effect of different machining techniques on the surface roughness of beech and spruce wood. They designed a test to consider the characteristics of sawn and sanded surfaces with 60 and 80 sandpapers. Pinkowski et al. [5] have studied the effect of cutting angle and feed rate on the surface roughness of different woods in the planning process. They performed experiments with four different cutting angles of the blade, four different feed rates, and constant rotational speed. They found that surface roughness decreases with decreasing cutting angle and surface roughness increases with increasing feed rate. The optimal cutting angle is 40 degrees. Moreover, the surface area decreases with increasing wood density. Extensive research [6–10] has been conducted to investigate cutting parameters on different woods in the planning process. Koch et al. [11] have studied the effects of feed rate and spindle rotational speed on two types of wood and MDF in the CNC milling process. They used the factorial method in the design of the experiment and found that a smoother surface was obtained by increasing the rotational speed of the spindle and decreasing the feed rate. Bal and AKÇAKAYA [12] have studied the effect of step over, feed rate, and cutting depth on fiber surface roughness in the CNC machining process. They performed experiments on two cutting depths of 2 and 6 (mm), step over of 40, 60, and 80% of the tool diameter, feed rate of 3, 5, 7 (m/min) and a constant spindle speed of the spindle. They found that the feed rate and surface roughness increase with increasing the depth of cut. In the design of traditional experimental methods, only one factor was considered as a variable and other factors were constant. In this method, due to the existence of one variable, the effects between the variables are not studied and the full effect of the variables on the response is not displayed. In addition, to do the project in the mentioned method, many tests are needed, which leads to an increase in time and cost as well as an increase in the consumption of materials. To overcome this problem, the response surface methodology (RSM) was proposed by Box and Wilson for optimization studies [13]. RSM is a mathematical tool that determines the relationship between a set of responses and independent variables. An important aspect of RSM is design of experiments, commonly known as DOE. This strategy was originally developed to fit experimental models but can also be used for numerical experiments. DOE's goal is to select the points where the response should be evaluated. The test design can have a great impact on the accuracy of the estimation and the cost of constructing the response surface model. Rao and Murthy [14] have studied the effect of cutting parameters on the surface roughness and workpiece vibrations using experimental design methods including the RSM in the drilling process. Moreover, Hazir and Koc [15] have investigated the optimization of cutting parameters in the CNC process of Lebanese Cedar and European black pine with the aim of minimum surface roughness using RSM. Extensive research [16–19] has been done on modeling and optimization of cutting parameters to achieve the desired surface roughness by using the RSM method.

This research has been conducted to determine the effective parameters in machining of beech wood to achieve the best surface quality. Afterwards, the effect of machining parameters such as feed rate, spindle speed, cutting depth, and step over on beech wood surface roughness have been studied. Finally, Optimization modeling has been performed under RSM, and the mentioned parameters have been optimized to achieve the minimum surface roughness of the workpiece.

2. Materials and Methods

Woodworking with CNC technologies is an integral part of the woodworking industry, and there are various methods to achieve the desired smooth surface that is important in high-performance machining and high-quality production. In this section, the workpiece material and the utilized CNC machine and tool are introduced. The conditions and methods of testing and machining and the optimization method are also explained.

2.1. Test Materials and Conditions

The wood used in this research is beech wood, which is widely used for wooden products due to its stable internal structure, high density and good compressive strength performance. The physical and mechanical properties of beech wood have been studied in recently published literature [20–22]. Here, the details for the under-study wood mechanical properties are listed in Table 1. Pieces of this wood with dimensions of 10*30 (cm) and a thickness of 15 (mm) in the radial direction have been prepared for testing. The machine used for milling is a three-axis cartesian CNC with a Mach3 control system. The zigzag strategy has been used for the end milling of the desired surface in ArtCAM software. Here, the end mill series used are ARDEN 214, which are ideal for high volume end mills with medium feed rates due to their hard materials and diamond crystal structure. The end mill tool code 214,214 has a working height of 12 (mm) and a diameter of 20 (mm) with two tungsten carbide teeth.

Table 1. Mechanical properties of under study beech wood [21].

Bending Strength	Elasticity Modulus	Grain Parallel Compression	Grain Parallel Shear Strength	Grain Parallel Tensile Strength	Grain Normal Tensile Strength	Impact Bending
99.01 (MPa)	11,224 (MPa)	57.05 (MPa)	10.47 (MPa)	131.15 (MPa)	3.71 (MPa)	11.081 (KJ/m^2)

2.2. Experimentation

As the response surface method is one of the common statistical methods in the design of experiments, in the present study Design-Expert software and the response surface method have been used to design the experiments and analyze the results. In this method, the variables affecting the response and the minimum and maximum limits are determined, and based on these limits and the model the test matrix is designed. One of the main advantages of this method over the full factorial method is the reduction in the number of experiments while the number of variables is high, which reduces the costs and time of the research. The three main types of response surface methods are the central composite, Box Benken, and Dehlert models, in which the central composite model used in this paper is more valid than the others [23]. Work piece material, machine tool type, and geometric factors may be varied during machining [24]. Required surface quality can be attained by proper machining parameters selection. Here, in a milling condition with the given factors for the machine tool and work piece material, surface quality can be determined and improved depending on the geometric factors' selection which includes feed rate, cutting speed, step over, and depth of cut [25–27]. The effective variables considered on the surface roughness method and their minimum and maximum values are presented in Table 2.

Table 2. Minimum and maximum input data.

Parameter	Maximum	Minimum
Depth of cut (mm)	10	4
Feed rate (mm/s)	55	30
Spindle speed (rpm)	15,000	9000
Step over (mm)	7.75	5.25

By importing the data listed in Table 1 into the Design-Expert environment and using the central composite model for the response surface method, the test conditions have been designed according to the Table 3. The total number of experiments can also be obtained by the following equation:

$$N = 2^k + 2k \tag{1}$$

where N is the total number of experiments and k is the number of independent variables.

Table 3. Experimental test conditions.

No.	Step Over (mm)	Spindle Speed (rpm)	Feed Rate (mm/s)	Depth of Cut (mm)
1	7.75	9000	30	10
2	7.75	12,000	40	10
3	7.75	15,000	50	10
4	7.75	9000	35	8
5	7.75	12,000	45	8
6	5.25	12,000	55	8
7	5.25	15,000	55	8
8	7.75	15,000	45	8
9	6.5	15,000	45	8
10	5.25	9000	50	6
11	6.5	12,000	55	6
12	7.75	15,000	55	6
13	7.75	12,000	30	6
14	5.25	12,000	40	6
15	6.5	15,000	50	6
16	7.75	9000	40	6
17	7.75	9000	30	6
18	7.75	15,000	40	6
19	7.75	15,000	55	4
20	6.5	12,000	45	8
21	7.75	15,000	55	4
22	6.5	15,000	30	6
23	5.25	12,000	50	6
24	7.75	12,000	45	6

Surface roughness can be measured by tracing the probe across the workpiece surface. The arithmetical mean of the absolute values of the profile deviations, *Ra*, is a vertical parameter that shows the average roughness of a surface. After performing 24 designed tests the average roughness parameter (*Ra*) has been measured using a TIME 3202 digital roughness meter according to ISO 4287 standard [28], which uses five sampling lengths for *Ra* measurement. Figure 1 shows the machining process and average surface roughness measurement.

(**a**) (**b**)

Figure 1. (**a**) CNC machining of beech wood; (**b**) surface roughness measurement.

2.3. Response Surface Analysis

Response surface analysis is known as a time and cost economic method that makes it easy to identify the outlier data. This method has been adopted in various fields of study, and particularly in manufacturing research works [29–38]. Since the adjusted coefficient of determination R^2 represents the accuracy of the estimation concerning the roughness regression, it should be more than 90% to achieve the appropriate relation. Table 4 shows R^2 coefficient values for different equations. The value of this coefficient in the cubic equation is 100%, and it indicates the high accuracy of the estimated equation which has been utilized in this study.

Table 4. Regression models validation.

Regression Model	$Adj-R^2$	Valid
Linear $R_a(\mu m) = a_0 + a_1 f + a_2 n + a_3 a + a_4 s$	0.4480	
Linear + 2 factor interaction $R_a(\mu m) = a_0 + a_1 f + a_2 n + a_3 a + a_4 s + a_5 fn + a_6 na + a_7 as + a_8 sf$ $+a_9 fa + a_{10} ns$	0.5732	
Quadratic $R_a(\mu m) = a_0 + a_1 f + a_2 n + a_3 a + a_4 s + a_5 f^2 + a_6 n^2 + a_7 a^2 + a_8 s^2$ $+a_9 fn + a_{10} na + a_{11} as + a_{12} sf + a_{13} fa + a_{14} ns$	0.4278	
Cubic $R_a(\mu m) = a_0 + a_1 f + a_2 n + a_3 a + a_4 s + a_5 f^2 + a_6 n^2 + a_7 a^2 + a_8 s^2$ $+a_9 fn + a_{10} na + a_{11} as + a_{12} sf + a_{13} fa + a_{14} ns$ $+a_{15} f^3 + a_{16} n^3 + a_{17} a^3 + a_{18} s^3 + a_{19} afn + a_{20} afs$ $+a_{21} ans + a_{22} fns + a_{23} a^2 f + a_{24} a^2 n + a_{25} a^2 s$ $+a_{26} af^2 + a_{27} an^2 + a_{28} as^2 + a_{29} f^2 n + a_{30} f^2 s$ $+a_{31} fn^2 + a_{32} fs^2 + a_{33} ns^2 + a_{34} n^2 s$	1	×

2.4. Variance Analysis

ANOVA (analysis of variance) is a statistical analysis used to determine the model's suitability. Table 5 shows the results of ANOVA for the third-order equation of Ra, where the p-value shows the significance of each coefficient. If the p-value becomes less than 0.05 it indicates the coefficient's significance and importance. Considering Table 5, all parameters of a third-order equation, including the third power of the parameters, are presented in the estimated equation. The total p-value of the equation is 0.0014, and therefore the estimated model is valid. The estimated coefficient of each parameter is also shown on the general model, which has the greatest effect on the feed rate that is equal to 31.47.

Table 5. Analysis of variance results.

Parameter	p-Value	Predicted Coefficient
Constant		22.26
Linear		
a	0.0031	10.75
f	0.0016	31.47
n	0.0013	−11.24
s	0.0012	9.88
Quadratic		
a^2	0.0072	2.80
f^2	0.0015	15.89
n^2	0.0012	1.93
s^2	0.0016	2.04
2 Factor interaction		
af	0.0026	19.51
an	0.0012	−11.87
as	0.0015	7.04
fn	0.0017	−9.14
fs	0.0012	10.44
ns	0.0015	−5.62
afn	0.0015	−8.44
afs	0.0014	7.62
ans	0.0022	1.58
fns	0.0014	−5.08
$a^2 f$	0.0061	2.31

Table 5. *Cont.*

Parameter	p-Value	Predicted Coefficient
2 Factor interaction		
a^2n	0.0075	−1.41
af^2	0.0021	10.83
f^2n	0.0048	−1.10
Total	0.0014 (Significant)	

3. Results and Discussions

3.1. The Effect of Different Machining Parameters on Surface Roughness of Beech Wood

The effect of different machining parameters on surface roughness of other workpiece materials has been studied in several research works. In the literature [39–41] it was reported that the control parameters having the most effect on surface quality are the spindle speed, feed rate and depth of cut rate, and that better surface quality was obtained at higher spindle speeds, lower feed rates and depth of cut. In this study similar results have been obtained for the effect of spindle speed, feed rate, and depth of cut on surface quality of the beech wood. Particularly, the step-over effect on the surface roughness has been investigated in this study.

Figure 2 shows the effect of machining parameters on surface roughness. According to Figure 2a, which presents the effect of spindle speed on surface roughness, when the spindle speed increases the surface roughness increases as well. Moreover, this figure shows that the surface roughness increases with the increase in cutting depth. Figure 2b shows the effects of feed rate and surface roughness on cutting depth, where it is seen that if the feed rate increases the surface roughness increases, and with the increase in the cutting depth the surface roughness also increases. Figure 2c also shows the effects of cutting depth and surface roughness on step over. It can also be obtained from this figure that increasing the depth of cut leads to an increase in surface roughness. Significantly, with the increase in the step over, the surface roughness continues to increase.

Figure 2d illustrates the effects of spindle speed and surface roughness on the step over. As the spindle speed increases the surface roughness increases. With an increase in step over the surface roughness increases as well. Figure 2e shows the effects of step over and surface roughness on to the feed rate, and it is apparent that the step-over increase leads to the surface roughness increase. Per Figure 2f that presents the effects of spindle speed and surface roughness on feed rate, one can understand that the higher spindle speed or feed rate results in the higher surface roughness increases.

3.2. Parameter Optimization

The focus of the present work is to reduce the surface roughness of the workpiece to achieve the desired surface quality. Optimal machining parameters can be used to minimize the desired workpiece surface roughness. Table 6 shows the optimal machining parameters that are obtained here using the response surface method.

Table 6. Goal and optimized value of parameters.

Parameter	Goal	Description	Optimized Value
Depth of cut	Maximum	Increase in production rate	10
Feed rate	Maximum	Increase in production rate	66.262
Spindle speed	In range		15,000
Step over	In range		5.25
Surface roughness	Minimum	Increase in product quality	4.2
		Desirability	0.812

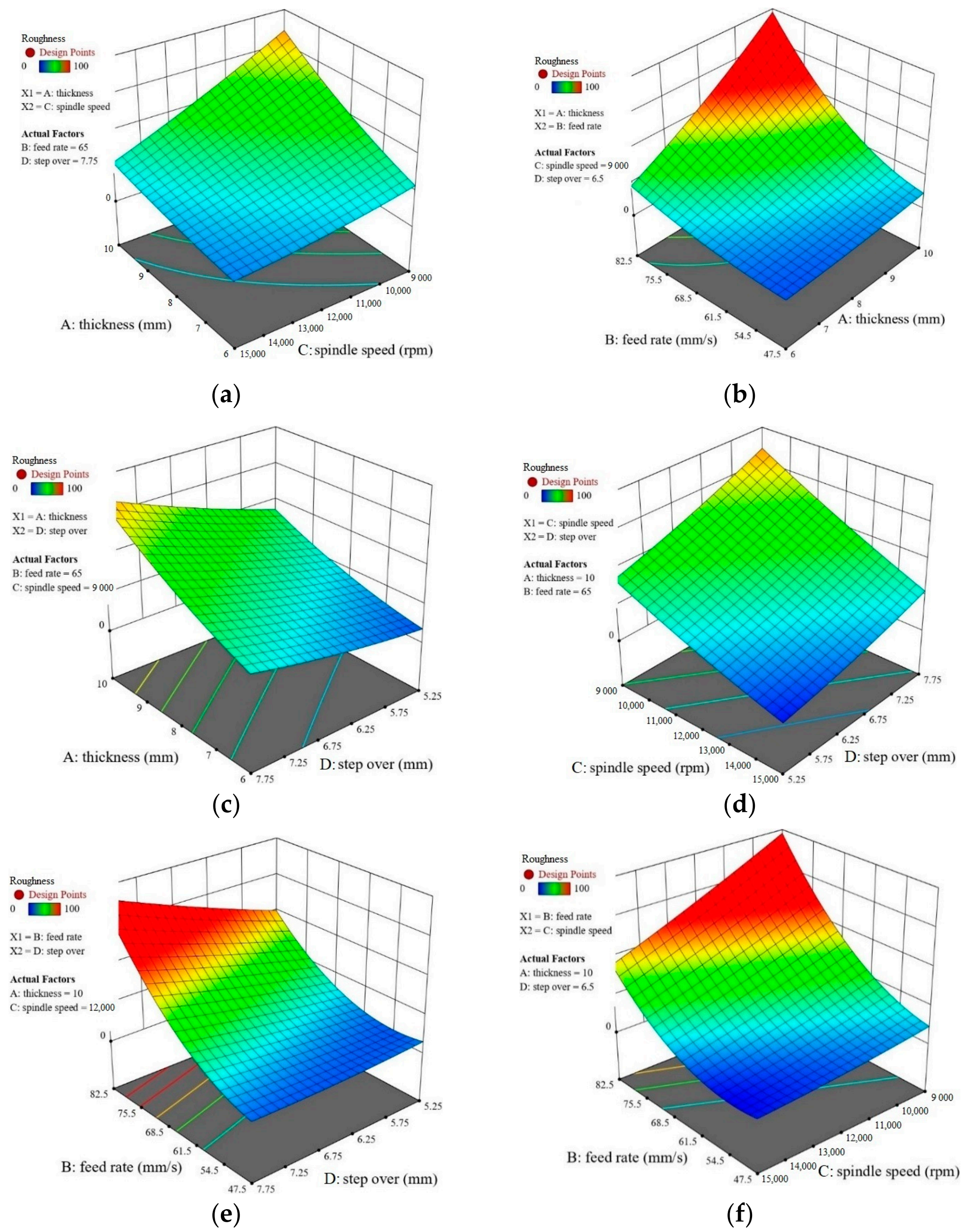

Figure 2. Effect of machining parameters on surface roughness: (**a**) effects of spindle speed and depth of cut on surface roughness; (**b**) effects of feed rate and depth of cut on surface roughness; (**c**) effects of depth of cut and step over on surface roughness; (**d**) effects of spindle speed and step over on surface roughness; (**e**) effects of step over and feed rate on surface roughness; (**f**) effects of spindle speed and feed rate on surface roughness.

By analyzing the results obtained from the optimization, the optimal value of *Ra* can be obtained based on the estimated model. This value is equal to 4.2 (μm) (Figure 3). As the desirability value approaches 1, a better optimization result will be obtained.

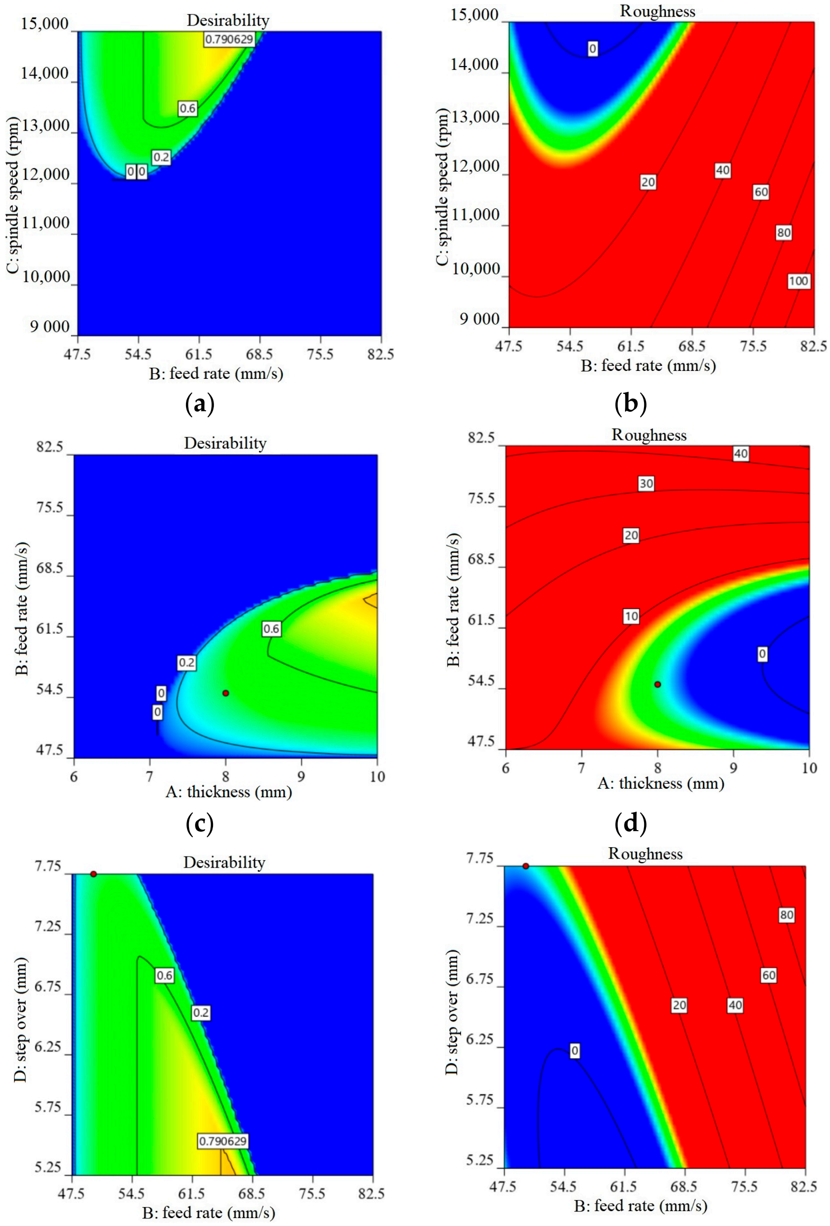

Figure 3. Effect of machining parameters and graphical analysis for surface roughness and desirability: (**a**) spindle speed and feed rate on desirability; (**b**) spindle speed and feed rate on roughness; (**c**) feed rate and thickness on desirability; (**d**) feed rate and thickness on roughness; (**e**) feed rate and step over on desirability; (**f**) feed rate and step over on roughness.

The optimized results' ramps are illustrated in Figure 4. The red bullets represent the optimized values and the blue bullet represents how well the surface quality increased. The relevant bar graph of desirability for the machining condition, replies, and the combined desirability of 0.812 is presented in Figure 5 that shows the overall desirability of all the parameters and the response.

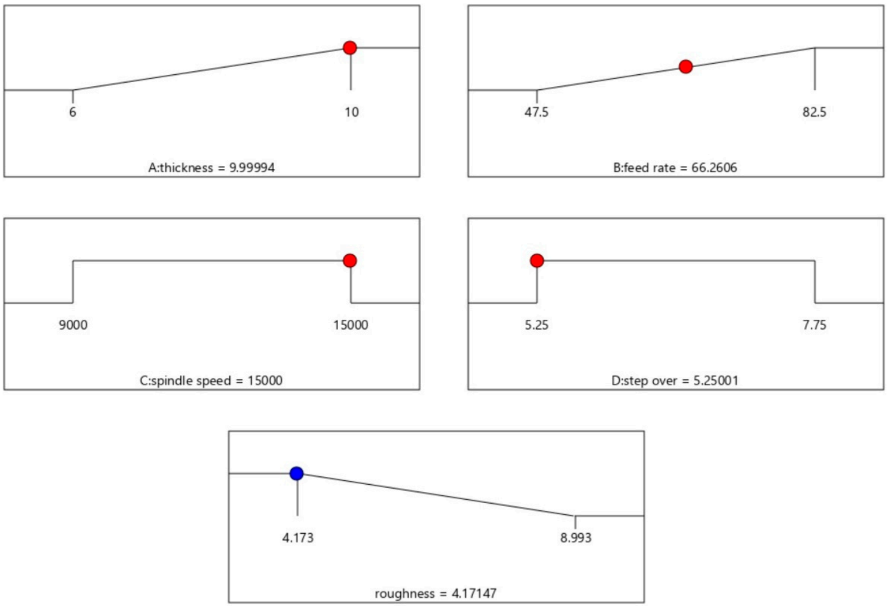

Figure 4. The graphs for optimal parameter ramp's function and combined optimization.

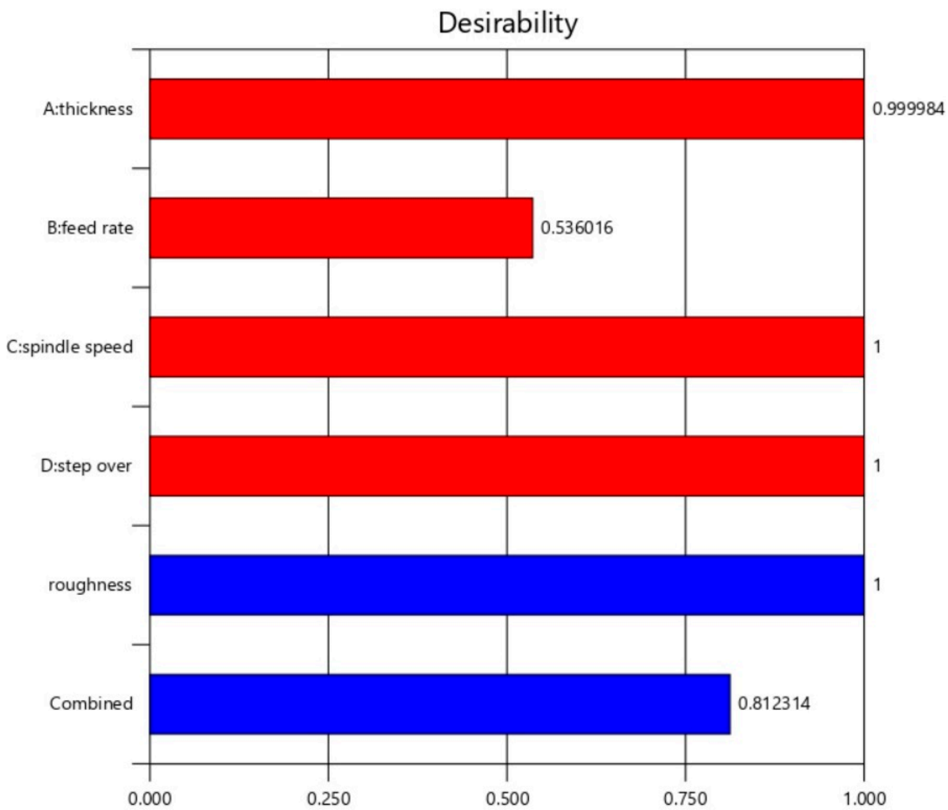

Figure 5. Desirability bar graph for combined optimization.

3.3. Model Validation

To validate the proposed model, the estimated surface roughness value and the value obtained from the model measurement have been compared here. Table 7 shows the estimated and measured values in different model conditions. According to this table the measured and estimated values are equal or have a slight difference with each other. Therefore, the estimated model has enough accuracy to calculate surface roughness based on different machining parameters (feed rate, spindle speed, depth of cut, step over).

Table 7. Comparison of surface roughness values measured and predicted by the model.

Condition	95 % PI High	95 % PI Low	Std Dev	Roughness Measured Value	Roughness Predicted Value by Model
1	8.52612	8.44988	0.003	8.488	8.488
2	7.38712	7.31088	0.003	7.349	7.349
3	5.25612	5.17988	0.003	5.218	5.218
4	6.70112	6.62488	0.003	6.663	6.663
5	7.06512	6.98888	0.003	7.027	7.027
6	7.63512	7.55888	0.003	7.597	7.597
7	5.92112	5.84488	0.003	5.883	5.883
8	6.95712	6.88088	0.003	6.919	6.919
9	6.79412	6.71788	0.003	6.756	6.756
10	7.53112	7.45488	0.003	7.493	7.493
11	7.84812	7.77188	0.003	7.81	7.81
12	8.01412	7.93788	0.003	7.976	7.976
13	5.27812	5.20188	0.003	5.24	5.24
14	7.52612	7.44988	0.003	7.488	7.488
15	6.78812	6.71188	0.003	6.75	6.75
16	9.03112	8.95488	0.003	8.993	8.993
17	8.02412	7.94788	0.003	7.986	7.986
18	5.10712	5.03088	0.003	5.069	5.069
19	7.87251	7.80649	0.002598	7.838	7.8395
20	7.08212	7.00588	0.003	7.044	7.044
21	7.87251	7.80649	0.002598	7.841	7.8395
22	4.21112	4.13488	0.003	4.173	4.173
23	7.46212	7.38588	0.003	7.424	7.424
24	6.30112	6.22488	0.003	6.263	6.263

4. Conclusions

This research mainly focuses on parameters investigation and optimization to achieve the best surface quality for the machined beech wood. The effect of machining parameters on the surface roughness of a piece of beech wood was investigated. RSM method is used to design experiments and the results are analyzed using Design-Expert. The studied parameters were optimized to achieve the minimum surface roughness. The summary of the obtained results is as follows:

- The roughness of surface decreased with decreasing feed rate. Changes in surface roughness due to the feed rate changes at high load depth, low spindle speed, and high step were very significant. Moreover, the surface roughness increased with an increasing pitch;
- The surface roughness increased with increasing the depth of cut. At this step, changes in surface roughness were very noticeable due to the changes in cutting depth, low spindle speed and high feed rate. In addition, as the spindle speed decreased, the surface roughness increased accordingly. Changes in surface roughness due to changes in spindle speed at high depth of cut, step over, and feed rate were very noticeable;
- The third-order mathematical model was modeled by the response surface method to estimate surface roughness based on machining parameters (feed rate, spindle speed, depth of cut and step by step). ANOVA showed that the greatest effect on surface roughness was related to the feed rate.

Finally, the optimal parameters for minimizing the surface roughness were obtained by the response surface method. Feed rate 66.262 (mm/s), spindle speed 15000 (rpm), cutting depth 10 (mm) and pitch 5.25 (mm). Moreover, the best surface roughness was obtained 4.2 (μm).

The results of the proposed model for the estimated surface roughness value were evaluated by the value obtained from the model measurement. The measured and estimated values are equal or have a slight difference. Finally, it can be concluded that the model has a good accuracy to predict surface roughness based on different machining parameters. As RSM allows investigating the influences of multiple factors and their interactions on one or more response variables, for future works this method can be applied to other factors influential on surface quality, and can even be employed to investigate the effects of the mentioned parameters on other response variables such as tool wear. This produces high-precision machining and high-quality wooden products. The study can also be continued on other wood types to study the product cost and quality. This, moreover, clearly shows the applicability and significance of the method in other studies in terms of economical cost, time, and any other limitations.

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References

1. Fujiwara, Y.; Fujii, Y.; Sawada, Y.; Okumura, S. Assessment of wood surface roughness: Comparison of tactile roughness and three-dimensional parameters derived using a robust Gaussian regression filter. *J. Wood Sci.* **2004**, *50*, 35–40. [CrossRef]
2. Usta, I.; Demirci, S.; Kiliç, Y. Comparison of surface roughness of Locust acacia (*Robinia pseudoacacia* L.) and European oak (*Quercus petraea* (Mattu.) Lieble.) in terms of the preparative process by planing. *Build. Environ.* **2007**, *42*, 2988–2992. [CrossRef]
3. Hernández, R.E.; Kuljich, S.; Koubaa, A. Effect of cutting width and cutting height on the surface quality of black spruce cants produced by a chipper-canter. *Wood Fiber Sci.* **2010**, *42*, 273–284.
4. Kılıç, M.; Hiziroglu, S.; Burdurlu, E. Effect of machining on surface roughness of wood. *Build. Environ.* **2006**, *41*, 1074–1078. [CrossRef]
5. Pinkowski, G.; Szymański, W.; Krauss, A.; Stefanowski, S. Effect of sharpness angle and feeding speed on the surface roughness during milling of various wood species. *BioResources* **2018**, *13*, 6952–6962. [CrossRef]
6. Hiziroglu, S.; Kosonkorn, P. Evaluation of surface roughness of Thai medium density fiberboard (MDF). *Build. Environ.* **2006**, *41*, 527–533. [CrossRef]
7. Keturakis, G.; Juodeikiene, I. Investigation of milled wood surface roughness. *Mater. Sci.* **2007**, *13*, 47–51.
8. Malkoçoğlu, A. Machining properties and surface roughness of various wood species planed in different conditions. *Build. Environ.* **2007**, *42*, 2562–2567. [CrossRef]
9. Davim, J.P.; Clemente, V.C.; Silva, S. Surface roughness aspects in milling MDF (medium density fibreboard). *Int. J. Adv. Manuf. Technol.* **2008**, *40*, 49–55. [CrossRef]
10. Barcík, Š.; Pivolusková, E.; Kminiak, R.; Wieloch, G. The influence of cutting speed and feed speed on surface quality at plane milling of poplar wood. *Wood Res.* **2009**, *54*, 109–116.
11. Koc, K.H.; Erdinler, E.S.; Hazir, E.; Öztürk, E. Effect of CNC application parameters on wooden surface quality. *Measurement* **2017**, *107*, 12–18. [CrossRef]
12. Bal, B.C.; Akçakaya, E. The effects of step over, feed rate and finish depth on the surface roughness of fiberboard processed with CNC machine. *Furnit. Wooden Mater. Res. J.* **2018**, *1*, 86–93. [CrossRef]
13. Box, G.E.P.; Wilson, K.B. On the Experimental Attainment of Optimum Conditions. *J. R. Stat. Soc. Ser. B* **1951**, *13*, 1–38. [CrossRef]
14. Venkata Rao, K.; Murthy, P.B.G.S.N. Modeling and optimization of tool vibration and surface roughness in boring of steel using RSM, ANN and SVM. *J. Intell. Manuf.* **2018**, *29*, 1533–1543. [CrossRef]
15. Hazir, E.; Koc, K.H. Optimization of wood machining parameters in CNC routers: Taguchi orthogonal array based simulated angling algorithm. *Maderas Cienc. Tecnol.* **2019**, *21*, 493–510. [CrossRef]
16. Selaimia, A.-A.; Yallese, M.A.; Bensouilah, H.; Meddour, I.; Khattabi, R.; Mabrouki, T. Modeling and optimization in dry face milling of X2CrNi18-9 austenitic stainless steel using RMS and desirability approach. *Measurement* **2017**, *107*, 53–67. [CrossRef]

17. Asiltürk, I.; Neşeli, S.; Ince, M.A. Optimisation of parameters affecting surface roughness of Co28Cr6Mo medical material during CNC lathe machining by using the Taguchi and RSM methods. *Measurement* **2016**, *78*, 120–128. [CrossRef]
18. Sarıkaya, M.; Güllü, A. Taguchi design and response surface methodology based analysis of machining parameters in CNC turning under MQL. *J. Clean. Prod.* **2014**, *65*, 604–616. [CrossRef]
19. Prakash, S.; Palanikumar, K. Modeling for prediction of surface roughness in drilling MDF panels using response surface methodology. *J. Compos. Mater.* **2010**, *45*, 1639–1646. [CrossRef]
20. Skarvelis, M.; Mantanis, G.I. Physical and mechanical properties of beech wood harvested in the Greek public forests. *Wood Res.* **2013**, *58*, 123–130.
21. Najafian Ashrafi, M.; Shaabani Asrami, H.; Vosoughi Rudgar, Z.; Ghorbanian Far, M.; Heidari, A.; Rastbod, E.; Jafarzadeh, H.; Salehi, M.; Bari, E.; Ribera, J. Comparison of Physical and Mechanical Properties of Beech and Walnut Wood from Iran and Georgian Beech. *Forests* **2021**, *12*, 801. [CrossRef]
22. Purba, C.Y.C.; Dlouha, J.; Ruelle, J.; Fournier, M. Mechanical properties of secondary quality beech (*Fagus sylvatica* L.) and oak (*Quercus petraea* (Matt.) Liebl.) obtained from thinning, and their relationship to structural parameters. *Ann. For. Sci.* **2021**, *78*, 81. [CrossRef]
23. Montgomery, D.C. *Design and Analysis of Experiments*, 7th ed.; John and Wiley and Sons: Hoboken, NJ, USA, 2009.
24. Groover, M.P. *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*, 4th ed.; John and Wiley and Sons: Hoboken, NJ, USA, 2010.
25. Sharma, A.; Dwivedi, V.K. Effect of milling parameters on surface roughness: An experimental investigation. *Mater. Today Proc.* **2019**, *25*, 868–871. [CrossRef]
26. Arun Premnath, A.; Alwarsamy, T.; Abhinav, T.; Krishnakant, C.A. Surface roughness prediction by response surface methodology in milling of hybrid aluminium composites. *Procedia Eng.* **2012**, *38*, 745–752. [CrossRef]
27. Sanjeevi, R.; Nagaraja, R.; Radha Krishnan, B. Vision-based surface roughness accuracy prediction in the CNC milling process (Al6061) using ANN. *Mater. Today Proc.* **2021**, *37*, 245–247. [CrossRef]
28. *ISO 4287:1997*; Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Terms, Definitions and Surface Texture Parameters. International Organization for Standardization: Geneva, Switzerland, 1997.
29. Bakhaidar, R.B.; Naveen, N.R.; Basim, P.; Murshid, S.S.; Kurakula, M.; Alamoudi, A.J.; Bukhary, D.M.; Jali, A.M.; Majrashi, M.A.; Alshehri, S.; et al. Response Surface Methodology (RSM) Powered Formulation Development, Optimization and Evaluation of Thiolated Based Mucoadhesive Nanocrystals for Local Delivery of Simvastatin. *Polymers* **2022**, *14*, 5184. [CrossRef]
30. Gutema, E.M.; Gopal, M.; Lemu, H.G. Minimization of Surface Roughness and Temperature during Turning of Aluminum 6061 Using Response Surface Methodology and Desirability Function Analysis. *Materials* **2022**, *15*, 7638. [CrossRef]
31. Chen, C.-P.; Su, H.-Z.; Shih, J.-K.; Huang, C.-F.; Ku, H.-Y.; Chan, C.-W.; Li, T.-T.; Fuh, Y.-K. A Comparison and Analysis of Three Methods of Aluminum Crown Forgings in Processing Optimization. *Materials* **2022**, *15*, 8400. [CrossRef]
32. Oniszczuk-Świercz, D.; Świercz, R.; Michna, Š. Evaluation of Prediction Models of the Microwire EDM Process of Inconel 718 Using ANN and RSM Methods. *Materials* **2022**, *15*, 8317. [CrossRef]
33. Kang, H.; Liu, Y.; Li, D.; Xu, L. Study on the Removal of Iron and Manganese from Groundwater Using Modified Manganese Sand Based on Response Surface Methodology. *Appl. Sci.* **2022**, *12*, 11798. [CrossRef]
34. Khashi'Ie, N.S.; Waini, I.; Mukhtar, M.F.; Zainal, N.A.; Bin Hamzah, K.; Arifin, N.M.; Pop, I. Response Surface Methodology (RSM) on the Hybrid Nanofluid Flow Subject to a Vertical and Permeable Wedge. *Nanomaterials* **2022**, *12*, 4016. [CrossRef] [PubMed]
35. Equbal, A.; Equbal, M.A.; Equbal, M.I.; Ravindrannair, P.; Khan, Z.A.; Badruddin, I.A.; Kamangar, S.; Tirth, V.; Javed, S.; Kittur, M.I. Evaluating CNC Milling Performance for Machining AISI 316 Stainless Steel with Carbide Cutting Tool Insert. *Materials* **2022**, *15*, 8051. [CrossRef] [PubMed]
36. Alawad, M.O.; Alateyah, A.I.; El-Garaihy, W.H.; BaQais, A.; Elkatatny, S.; Kouta, H.; Kamel, M.; El-Sanabary, S. Optimizing the ECAP Parameters of Biodegradable Mg-Zn-Zr Alloy Based on Experimental, Mathematical Empirical, and Response Surface Methodology. *Materials* **2022**, *15*, 7719. [CrossRef] [PubMed]
37. Yanis, M.; Mohruni, A.S.; Sharif, S.; Yani, I.; Arifin, A.; Khona'Ah, B. Application of RSM and ANN in Predicting Surface Roughness for Side Milling Process under Environmentally Friendly Cutting Fluid. *J. Phys. Conf. Ser.* **2019**, *1198*, 042016. [CrossRef]
38. Zerti, A.; Yallese, M.A.; Zerti, O.; Nouioua, M.; Khettabi, R. Prediction of machining performance using RSM and ANN models in hard turning of martensitic stainless steel AISI 420. *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.* **2019**, *233*, 4439–4462. [CrossRef]
39. Ghazali, M.H.M.; Mazlan, A.Z.A.; Wei, L.M.; Tying, C.T.; Sze, T.S.; Jamil, N.I.M. Effect of Machining Parameters on the Surface Roughness for Different Type of Materials. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *530*, 012008. [CrossRef]
40. Zaidi, S.R.; Khan, M.; Jaffery, S.H.I.; Warsi, S. Effect of Machining Parameters on Surface Roughness During Milling Operation. *Adv. Manuf. Technol.* **2021**, *15*, 175–180. [CrossRef]
41. Zhenchao, Y.; Yang, X.; Yan, L.; Jin, X.; Quandai, W. The effect of milling parameters on surface integrity in high-speed milling of ultrahigh strength steel. *Procedia CIRP* **2018**, *71*, 83–88. [CrossRef]