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The Effect of the Aspect and Machining Parameters on CNC Machining of Solid Wood Material

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Abstract: The selection of wood materials in accordance with the place of use and their processing under the most appropriate conditions will ensure the utilisation of natural resources with high efficiency. In the utilisation of wood material, it is known that the characteristics of the place where it grows and the place where it grows affect the properties of the log and timber obtained. In this study, the surface roughness (*Ra*) values of larch (*Pinus nigra* Arnold) and eastern beech (*Fagus orientalis* Lipsky) wood species growing in northern and southern aspects were determined under various machining parameters. The specimens were grooved using a Scilled 2040 CNC 3-axis milling machine at 3 different feeds of 1000 mm/min, 1500 mm/min and 2000 mm/min, 12000 rpm, 15000 rpm and 18000 rpm, using a 12 mm diameter HSS (High-speed steel) cutter. The surface roughness parameter *Ra* was determined on the surfaces obtained, and the data obtained was evaluated. When evaluated in general, the lowest *Ra* value for both wood species was obtained at 18000 rpm at 1000 mm/min for larch and 1000 mm/min or 1500 mm/min for beech at a feed of 1000 mm/min or 1500 mm/min for the specimens obtained from the southern aspect. A linear decrease in Ra value occurred for both wood species with increased revolutions. The lowest *Ra* values were obtained at 18000 rpm. Generally, the samples obtained from the southern aspect direction gave smoother surfaces for both wood species.

Keywords: CNC, wood machining, aspect, surface roughness.

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1. INTRODUCTION

Wood material has been used in many areas to meet human needs. This situation reveals the necessity of more efficient use of natural resources, such as wood materials.

Especially for solid wood materials, it is seen that it is essential to obtain quality and smooth surfaces to carry out the machining in a short time; it is essential to obtain quality and smooth surfaces to carry out the processing quickly and to know the process characteristics.

Metals, plastics, wood and composite materials are essential engineering materials. These materials are machined using CNC machines such as CNC (computer numerical control) lathes, vertical machining centres, CNC milling machines and routers. In furniture factories, CNC routers are used to shape the surfaces of solid wood materials and extensively medium-density fibreboard (MDF). Some of these MDF boards are covered with PVC film to be used for cabinet doors, and others are painted. Today, scientific research is carried out in machining wood and wood-based materials with CNC machines, which is becoming widespread day by day.

There are many studies on CNC machining of solid and wood-based materials. Considering the studies conducted in recent years, surface roughness values in the machining of MDF decreased with an increase in cutting tool diameter and feed. In contrast, the values rose with an increase in spindle speed. The system was optimised using artificial neural networks (Demir et al., 2021). Dust particles generated in the CNC machining of MDF were examined, and it was revealed that the

amount of harmful particles can be reduced by optimising (Kminiak et al., 2021). The machining of heat-treated solid wood materials was investigated, and it was determined that the type of cutter milling cutter, feed and spindle speed were the most effective parameters on roughness (Pelit et al., 2021). Similar studies have been carried out on machining solid wood materials. Considering various machining parameters (speed, feed, cutter type, number of cutter teeth, depth of cut, cutter diameter, etc.), beech, oak, spruce and MDF (Kminiak et al., 2021), heat-treated pine, beech, linden (Pelit et al., 2021), maple (Gurau et al., 2022), walnut and ash (Çakıroğlu et al., 2022), MDFlam (Aktaş and Sofuoğlu, 2022a, 2022b), MDF (Dumanoglu and Bal, 2022), Bal et al., 2022; Açık, 2023), plywood, particleboard and MDF (Demir et al., 2022a; 2022b; Koleda et al., 2023), massive wooden edge-glued panels (Aktas and Sofuoglu, 2022), machining of densified wood materials (Sofuoglu et al., 2023; Tosun and Sofuoglu, 2023a; 2023b) were investigated.

Factors such as the regions where the trees from which the solid wood material is obtained grow, the climate and soil, etc., affect the properties of the wood material. This study aims to investigate the effect of growing conditions on the CNC machining of the wood material and the wood material's CNC machining and determine the optimum machining parameters considering the growing conditions and some basic CNC machining parameters. The aim is to increase productivity by obtaining the best surface quality of the wood material.

2. MATERIAL AND METHOD

In the selection of the tree species used within the scope of the study, larch (*Pinus nigra* Arnold) and eastern beech (*Fagus orientalis* Lipsky), which grow naturally at different elevations in the Simav district of Kütahya province, were selected. The selection of these wood species was influenced by the fact that they are widely grown and frequently used in the woodworking and furniture industry.

The logs (diameter, approximately 350 mm) (Figure 1) were turned into timber at a private enterprise in Kicir/Simav to obtain test specimens and kept in open-air conditions for natural drying (Figure 2). After drying the timber to a specific moisture content in natural drying, the conditioning of the samples was carried out at temperatures of (20 ± 2) °C and (65 ± 5) %, with a relative humidity of 12% moisture content (Figure 3).

Figure 1. Logs used in the preparation of test specimens

Figure 2. Natural drying of the lumber

The density of tree species was specified as larch south aspect 470 kg/m^3, larch north aspect 595 kg/m^3, eastern beech south aspect 684 kg/m^3, eastern beech north aspect 631 kg/m^3 (ISO 13061, 2014; ISO 13061-2, 2014).

Figure 3. Keeping the specimens in the air conditioning cabinet

The specimens, which were brought to 12% humidity in an air conditioning cabinet, were machined on a Scilled 2040 CNC 3-axis milling machine (maximum spindle speed = 18000 rpm) (Simav Faculty of Technology, Woodworking Industrial Engineering, Simav, Kutahya, Turkiye). New and sharp cutters were used. The experiments were carried out with a router cutter (Netmak, HSS 0450-08, 12 mm × 30 mm × 73 mm) that was 12 mm in diameter) (Figure 4).

Figure 4. Cutter type

Two parameters (feed and spindle speed) were used, and three levels were used in the experiment (Table 1).

Table 1. Assignment of levels to factors (wood species, feed, spindle speed and aspect)

Parameters	Level 1	Level 2	Level 3
Wood species	Beech	Larch	
Feed (mm/min)	1000	1500	2000
Spindle speed (rpm)	12000	15000	18000
Aspect	Northern	Southern	

The parameters used during CNC machining are given in Figure 5.

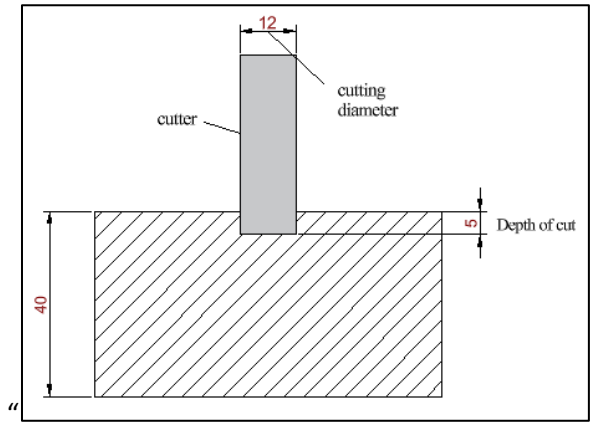

Figure 5. Parameters of the CNC process

A total of 108 pieces (54 northern + 54 southern) of dimensions of 12 mm x 60 mm were grooved on wood materials by a CNC router (Figure 6).

Surface roughness measurements were taken parallel to the grain on three separate lines on each specimen. The most preferred surface roughness parameter in the literature, average roughness (*Ra*) measurements were performed according to the protocols of ISO 24118-1 (2023), TS 2495 EN ISO 3274 (2005) and EN ISO 21920-3 (2022) principles.

Figure 6. CNC machining of specimens

Using a contact stylus trace method, the Surface Roughness Tester Time TR200 (Time Group Inc., China) was used to determine the *Ra* values (Figure 7). In this study, the Gaussian filter type was used. The sampling length was 0.8 mm, and the evaluation length was 4 mm. *Ra* values were measured with an accuracy of ± 0.01 µm. The speed of the stylus was 10 mm/min, the diameter of the stylus was 5 µm, and the angle of the stylus tip was 90°.

Figure 7. Roughness measurement of specimens

3. RESULTS AND DISCUSSION

Ra data obtained from trials with various parameters using specimens of beech and larch tree species are given in Table 2.

Table 2. *Ra* values obtained as a result of CNC machining under different machining conditions

Process No	Spindle speed (rpm)	Feed (mm/min)	Aspect	Beech (*Ra*, µm)	Larch (*Ra*, µm)
1	12000	1000	Northern	3.75	3.66
2	12000	1000	Southern	3.35	3.35
3	12000	1500	Northern	4.54	4.93
4	12000	1500	Southern	3.73	4.11
5	12000	2000	Northern	4.76	4.27
6	12000	2000	Southern	4.80	4.17
7	15000	1000	Northern	3.71	3.27
8	15000	1000	Southern	3.67	3.41
9	15000	1500	Northern	3.60	3.22
10	15000	1500	Southern	2.68	4.11
11	15000	2000	Northern	5.86	3.82
12	15000	2000	Southern	4.51	3.99
13	18000	1000	Northern	4.01	3.53
14	18000	1000	Southern	3.57	2.38
15	18000	1500	Northern	3.18	2.76
16	18000	1500	Southern	4.12	3.14
17	18000	2000	Northern	4.54	3.12
18	18000	2000	Southern	3.35	3.14

Figure 8 shows a probability plot for larch tree species, and Figure 9 shows a probability plot for beech tree species.

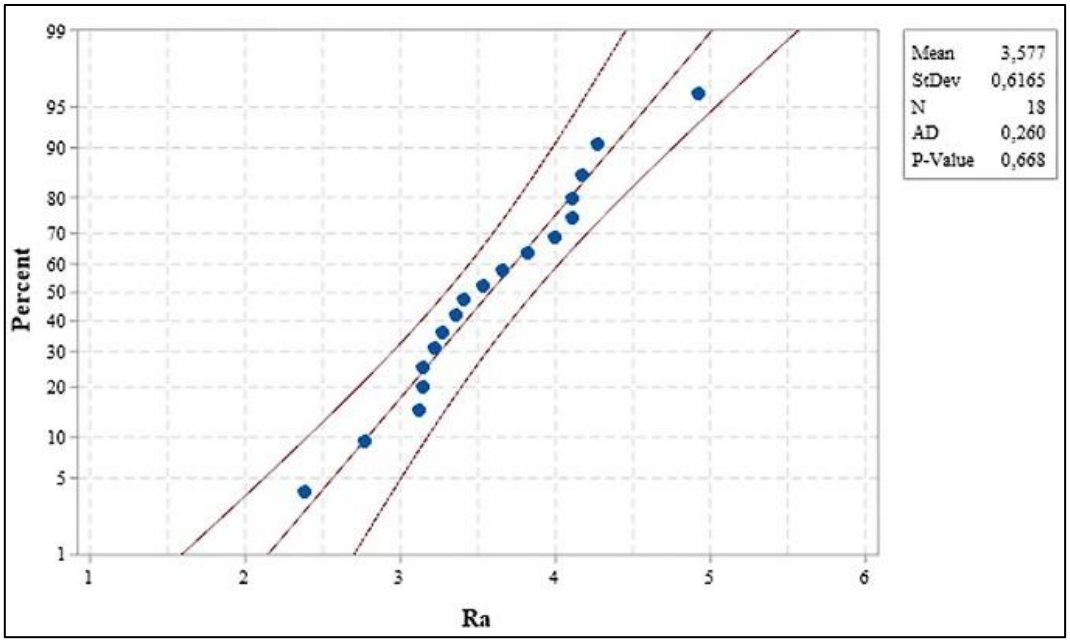

Figure 8. Probability plot for larch (*Ra*)

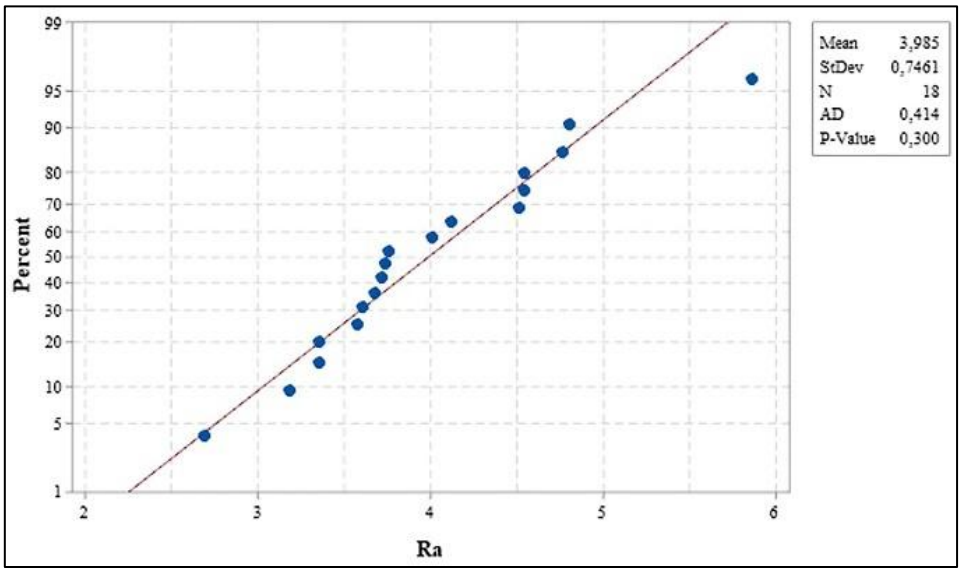

Figure 9. Probability plot for beech (*Ra*)

In the data obtained from the graphs, P=0.668>0.05 for larch and P=0.300>0.05 for beech, the Ra values are typically distributed at a 95% confidence level.

Table 3. ANOVA for larch wood machining

Source	DF	Adj SS	Adj MS	F-Value	*P*-Value
Spindle speed (rpm)	2	3.46710	1.73355	9.95	0.003
Feed (mm/min)	2	0.86970	0.43485	2.50	0.124
Aspect	1	0.03380	0.03380	0.19	0.667
Error	12	2.09100	0.17425		

According to the analysis of variance (ANOVA) in *Ra* in CNC machining of larch wood species obtained from north and south aspects, the effect of the number of revolutions (P=0.003<0.05) was found significant at a 95% confidence level. In contrast, the effect of feed (P=0.124>0.05) and aspect (P=0.667>0.05) was not found to be significant (Table 3).

As shown in Figure 10, as the speed increases from 12000 rpm to 18000 rpm, there is a linear decrease in *Ra* value. Ra value increases as the feed increases from 1000 mm/min to 2000 mm/min (the highest feed in CNC). The increase between 1000 and 1500 mm/min is higher than between 1500 mm/min and 2000 mm/min.

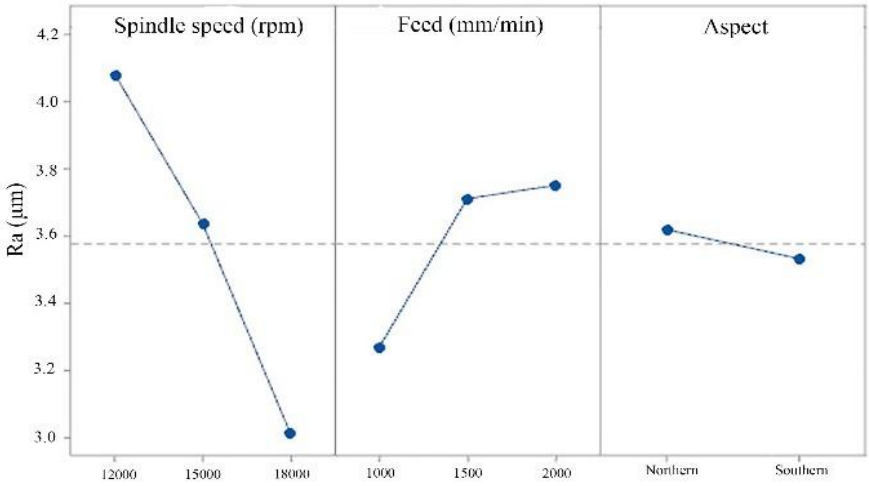

Figure 10. Effect of spindle speed, feed and aspect on larch (*Ra*) in measurements

When the literature is examined, it is seen that there are similar trends. It is known that when the feed is increased at the same speed, the number of cutter marks per unit distance decreases, and poorer surfaces are obtained. It is seen that similar results are obtained not only in CNC machining but also in the machining of solid wood materials such as planing, horizontal and vertical milling (Sofuoglu and Kurtoglu, 2014; Sofuoglu and Kurtoglu, 2015; Kaba and Bal, 2024). In terms of aspect, the Ra value was obtained lower on the surface obtained in the processing of wood species taken in the southern direction. The lowest *Ra* value for larch wood species was obtained at 18000 rpm at a feed of 1000 mm/min in the samples obtained from the southern direction.

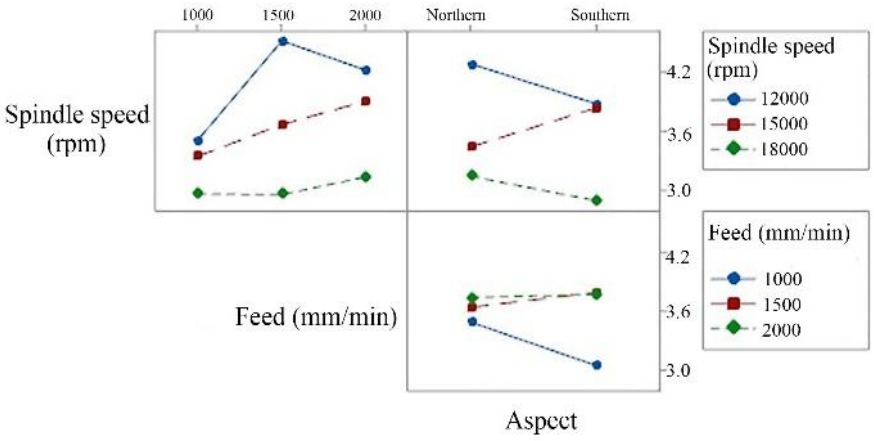

Figure 11. Interaction plot for larch

When the interactions in the machining of larch wood species in Figure 11 are examined, when the interaction graph for larch wood species is examined in the interaction of the spindle speed and feed, *Ra* values close to each other were obtained at 1000 mm/min at 12000 rpm and 15000 rpm. The highest *Ra* value occurred at 12000 rpm at a 1500 mm/min feed. Approximately close values were obtained at each feed at 18000 rpm. A linear Ra value increases as the feed increases at a spindle speed of 15000 rpm. When the interaction between view and spindle speed was analysed, very close values were obtained at 12000 and 15000 rpm in the specimens taken from the southern aspect. In the interaction of feed and aspect, close values were obtained at all three feeds in the northern aspect. In other words, the effect of the feed is very low in the north aspect.

Table 4. ANOVA for beech machining

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Spindle speed (rpm)	2	0.3924	0.1962	0.55	0.591
Feed (mm/min)	2	3.8257	1.9128	5.36	0.022
Aspect	1	0.9660	0.9660	2.71	0.126
Error	12	4.2799	0.3567		
Total	17	9.4641			

According to the results of the ANOVA in terms of *Ra* in CNC machining of beech wood species obtained from north and south aspects, the effect of feed (P=0.022<0.05) was found significant at a 95% confidence level. In contrast, the effect of the number of revolutions (P=0.591>0.05) and aspect (P=0.126>0.05) was not significant (Table 4).

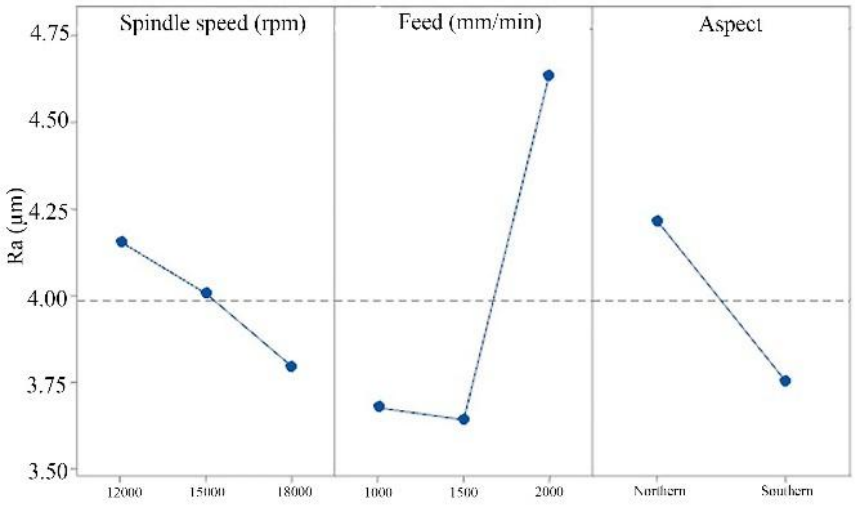

Figure 12. Effect of spindle speed, feed and aspect on beech (*Ra*) in measurements

As can be seen in Figure 8, there is a linear decrease in *Ra* value as the spindle speed increases from 12000 rpm to 18000 rpm. According to the obtained results, the surface roughness decreases with increasing spindle speed and increases with the feed (Davim et al., 2009; Sutcu and Karagoz, 2012; Sutcu, 2013; Sofuoglu, 2015; Koc et al. 2017; Hazir et al., 2017; Hazir and Koc, 2019; Bal et al., 2022; Tosun and Sofuoglu, 2023a; 2023b).

The reason for this is that smoother surfaces are obtained with the increase in the number of cutter marks per unit distance. Although this does not occur linearly in some studies, the lowest roughness values appear at the highest spindle speeds. It is thought that this is because the motors to which the cutters are connected to the shaft cause more vibration at certain speeds, and the machine's stability deteriorates during cutting. In addition, during idling at a spindle speed of 20000 rpm, the vibration was significant because of the resonance of the spindle head of the CNC (Ohuchi, 2001). While the Ra value between 1000 and 1500 mm/min shows a slight decrease, a significant increase occurs between 1500 mm/min and 2000 mm/min. Regarding aspect, the Ra value was lower in the faces obtained in machining tree species taken in the south direction. In both wood species, it is seen that smoother surfaces are obtained in the wood species taken from the southern aspect after machining. Smoother surfaces can be obtained in homogeneous wood materials with high density. However, in heterogeneous materials such as wood materials, if the density increase is due to slow growth in the parts where there are density changes, such as spring and autumn wood, these transitions may cause an increase in the roughness of the surface since the number of annual rings per unit distance will be high. It can be assumed that a similar situation is the case here. Generally, the lowest *Ra* value for beech wood species was obtained at 18000 rpm at a feed of 1500 mm/min (a similar value was obtained at 1000 mm/min) in the samples obtained from the southern aspect.

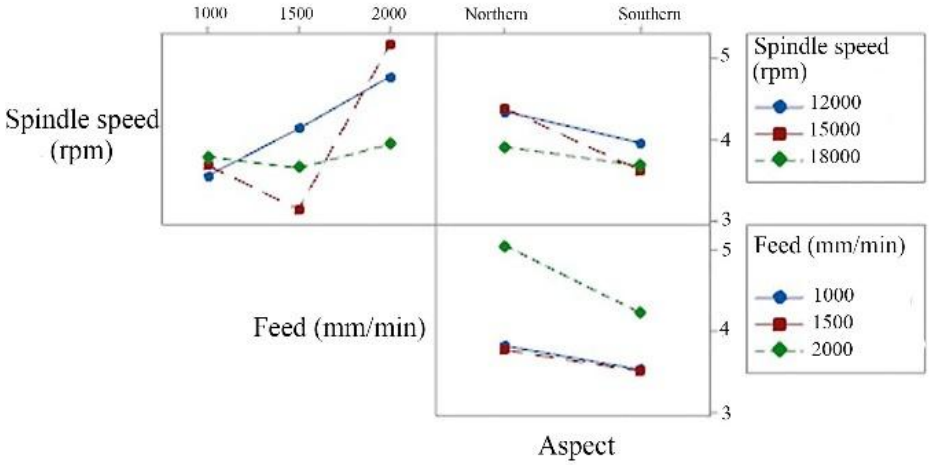

Figure 13. Interaction plot for beech

When the interaction graph for beech wood species is examined, a linear Ra value increases as the feed increases at 12000 rpm in the interaction of speed and feed. The highest Ra value occurred at 15000 rpm at 2000 mm/min feed. At 1000 mm/min feed, similar *Ra* values were obtained at all three speeds. In the interaction of aspect and speed, lower *Ra* values were obtained in the beech specimens obtained from the South direction at all three speeds. In the interaction of aspect and feed, the graphs were similar at 1000 and 15000 mm/min feed and although there was little difference, lower *Ra* values were obtained in the beech specimens grown in the south direction. In this interaction, the highest *Ra* value occurred at a 2000 mm/min feed in beech specimens obtained from the northern aspect.

4. CONCLUSIONS

In this study, larch (*Pinus nigra* Arnold) and eastern beech (*Fagus orientalis* Lipsky) wood species were selected as experimental materials. The wood species ' surface roughness (Ra) values were determined under various CNC machining conditions. The results obtained can be summarised as follows:

- While the effect of the number of revolutions was found to be significant for Larch in CNC machining, the effect of feed and angle was not found to be significant.
- While feed was significant for beech wood species, the effect of the number of revolutions and aspects was not significant.
- For both wood species, a linear decrease in *Ra* value occurred with increased spindle speed.
- Smoother surfaces were obtained by machining the wood samples from the southern aspect.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
Conceptualization: İ.İ., S.D.S.; Investigation: S.D.S.; Material and Methodology: İ.İ., S.D.S.; Supervision: S.D.S.; Visualization: İ.İ., S.D.S.; Writing-Original Draft: İ.İ., S.D.S.; Writing-review & Editing: İ.İ., S.D.S.

Conflict of Interest
The authors have no conflicts of interest to declare.

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