# Effects of Machining Methods on the Surface Roughness Values of *Pinus nigra* Arnold Wood

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In this study, samples were subjected to the following surface treatment techniques: sawing with a circular saw, planing with a thickness machine, and sanding with a sanding machine (with No. 80 sandpaper). After samples were treated radially and tangentially with machines, their surface roughness values ($R_a$, $R_y$, and $R_z$) were measured according to ISO 4288. When statistics related to surface roughness values (for $R_a$, $R_y$, and $R_z$) were analyzed, it was found that surfaces processed with the thickness machine exhibited the smoothest surfaces. Also, according to the same statistical tables, the lowest surface roughness values were found for surfaces cut tangentially.

*Keywords: Surface roughness; Pinus nigra Arnold wood; Wood machining; Cutting directions*

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## INTRODUCTION

The success of surface treatments in protecting wood as a final product and in increasing its visual appeal depends on the smoothness of its surface material (Richter *et al.* 1995). Also, the surface roughness of woody material significantly affects the general performance of the product in terms of the joining of wood with adhesive (Burdurlu *et al.* 2005). One of the most important criteria in the determination of a material's surface smoothness is surface roughness.

There are several factors influencing the surface roughness values of wood; these can be simply regarded as the annual ring variation, the density, the cell structure, and the latewood/earlywood ratio. The surface quality of the final product and accordingly its cost are also influenced by the machining used in manufacturing, the characteristics of the raw material, and/or the combination of these two parameters (Kilic *et al*. 2006).

Increased cutting speed, or rpm, generally results in the improved surface quality of wood products (McKenzie 1960; Lemaster and Beall 1993; Mitchell and Lemaster 2002; Kilic *et al*. 2006). The planed surface characteristic of solid wood is a function of its machining quality, which is directly related to knife marks per cm and not cutterhead speed alone (Davis 1962; Akbulut *et al*. 2000; Burdurlu *et al.* 2006).

Sand marks were also found to be important parameters influencing the quality of the surface. Grit size, and relatedly an alteration from the expected surface quality degree, would also result in a cost increase and wastage of raw material. Surface irregularities on solid wood are not always distinguished entirely compared to the other materials. Surface roughness of wood, at present, is defined using technical terms, given a representative or numerical reading of the surface topography. However, no universally accepted standard for the method has been established for these purposes, even though several methods are available such as stylus, optical profilometer, image analyses techniques-using a video camera, pneumatic, ultrasonic, and microscopy (Stumbo 1963; Faust 1987; Drew 1992; Funck *et al.* 1992; Hiziroglu *et al.* 2013; Salca and Hiziroglu 2014).

Each technique has relative advantages and disadvantages. Past studies have used the stylus method to determine the surface roughness of solid wood and wood composites (Peter and Cumming 1970; Ostman 1983; Hiziroglu and Suchsland 1993; Hiziroglu 1996; Aslan *et al.* 2008; Hiziroglu *et al.* 2013). A major advantage of the stylus method is that it provides an actual profile of the surface and standard numerical roughness parameters. Irregularities and magnitude of roughness can objectively be determined with this method. Thus, in this study, the fine stylus method was preferred to determine the surface roughness of machined wood samples prepared from *Pinus nigra* wood. The purpose was to determine the roughness of surfaces obtained by the most frequently used wood processing machines.

## EXPERIMENTAL

Experimental materials were obtained from the Çamkoru Dr. Fuat Adalı Research Forest of the Central Anatolia Forestry Research Institute.

The trees were cut in accordance with ISO 4471 (ISO 1982). The trees were selected based on the following criteria: regular, strong formation of the tree stem and crown; natural wood color; parallel fibers without any curliness; and no damage from insects and fungi. Furthermore, tree crowns that were cultivated in extremely humid or extremely dry areas, or in areas subjected to frequent wind and storms were avoided. Trees with intricate branches or with irregular crowns, as well as trees that were jammed between other trees were not selected.

Black pines were obtained from the Çamkoru Research Forest at an elevation of 1500 to 1550 m. Five trees were cut in total. After cutting, branches on the stems were grubbed, round timbers were sampled at above 0.3 m from the base, and the length of the trees and their diameters at 1.30 m were measured (Table 1).

**Table 1.** Properties of Experimental Trees

| | Black Pines | | | |
|---|---|---|---|---|
| Tree Number | Length (m) | Diameter at 1.30 m (cm) | Air dried density ($g/cm^3$) | Age (years) |
| 1 | 24 | 31 | 0.46 | 120 |
| 2 | 30 | 32 | 0.48 | 130 |
| 3 | 23 | 29 | 0.45 | 115 |
| 4 | 22 | 28 | 0.44 | 115 |
| 5 | 22 | 26 | 0.42 | 110 |
| Average air-dried density ($g/cm^3$)=0.45 | | | | |

Specimens were cut to dimensions of 60 x 500 mm in the Sample Preparing and Technology Laboratory of the Wood and Non-wood Forest Products Division of the Central Anatolia Forestry Research Institute. The specimens were then held in a conditioning room until they reached an air-dry moisture content of 12%.

Cutting direction and surface treatment were the main variables in the production of the samples. Two cutting directions (radial and tangential) and three surface treatment techniques (cutting by circular saw, planning, and sanding) were used in this work, and 180 measurements were taken with 30 test repetitions (2 x 3 x 30=180).

To assess the effects of different surface roughness values obtained with different surface processing techniques on the surface roughness of black pines, samples were subjected to the following operations in the appropriate time courses: lumbering, considering tangential and radial cutting directions and sample thicknesses and using a 40-tooth circular saw (6000 rpm); grating using a three-blade planer thicknesser (4500 rpm); and sanding using 80-grit sandpaper (1400 rpm). The feeding rate was constant at 10 m/min during processing. The type of operation was indicated by symbols on the front and back of the samples.

The Mitutoya Surftest-301 Series roughness tester, which takes measurements with the stylus method, was used to determine the effects of cutting direction, cutting with a circular saw, and planing and sanding on surface roughness. Measurements of surface roughness were made across the grain. The direction of measurement is displayed in Fig. 1.

The speed of the surface roughness measuring equipment used was 0.5 mm/s, the limit wavelength (λc) was 0.8 mm, and the measurement length (lt) was 21 mm (diamond tip stylus, tip angle 90°/tip radius 2 μm). At the end of the surface roughness replications, the $R_a$, $R_y$, and $R_z$ values of each piece were determined. Surface roughness values were determined in accordance with ISO 4288 (ISO 1996).

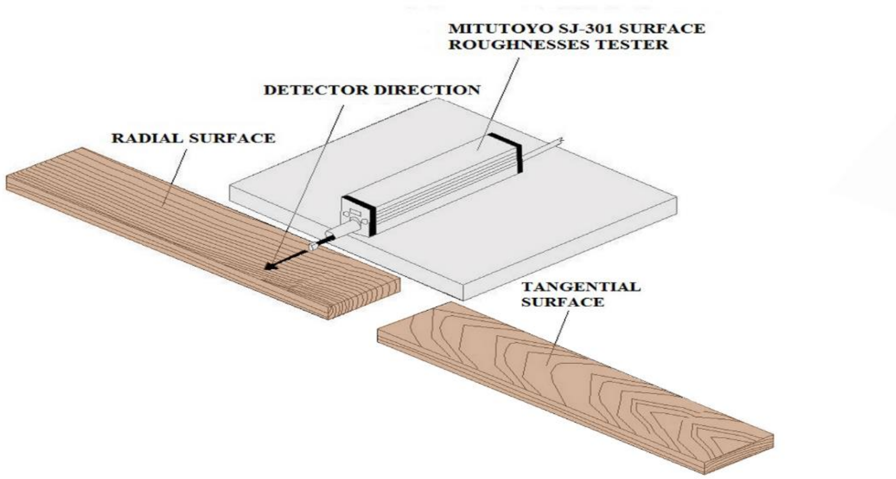


**Fig. 1.** Surface profilometer used in this study

## RESULTS AND DISCUSSION

### Evaluation of the Data Obtained for $R_a$ (Average Roughness)

The variance analysis calculated for $R_a$ from the surface roughness parameters is given in Table 2. According to the listed results, it was determined that in addition to machine type and cutting directions affecting the $R_a$ value, the dual effects of these variables on $R_a$ is statistically important. According to the results of the Tukey's test performed to compare the averages, the smoothest surfaces were obtained with the thickness machine ($R_a$=4.76 μm), followed by the sanding machine ($R_a$=5.06 μm) and the circular saw ($R_a$=7.01 μm) (Table 3).

In some studies, it was found that the surfaces obtained from thicknessers had smoother surfaces than those resulting from the sanding machine and circular saw (Aslan *et al.* 2008; İlter and Balkız 2005; İlter *et al.* 2002). Corresponding findings were also obtained in Burdurlu *et al.* 2006 (Table 5).

**Table 2.** Variance Analysis for $R_a$

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Squares | F | P |
|---|---|---|---|---|---|
| Machine(A) | 179.878 | 2 | 89.939 | 180.74 | 0.00* |
| Cutting Direction (B) | 7.667 | 1 | 7.667 | 15.408 | 0.00* |
| A*B | 11.893 | 2 | 5.94 | 11.950 | 0.00* |
| Error | 86.585 | 174 | 0.498 | | |
| Total | 5959.419 | 180 | | | |
| ns=(not significant)<br>*=<0.05 important | | | | | |

**Table 3.** Tukey's Test for $R_a$ According to Machine Type

| Machine | N | α=0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Thickness | 60 | 4.76 | | |
| Sanding | 60 | | 5.06 | |
| Circular | 60 | | | 7.01 |

When statistical values according to cutting direction (Table 4) were investigated, the average surface roughness values of the samples cut tangentially were found to be lower than the samples cut radially ($Ra_{Tangential}$=5.40 μm, $Ra_{Radial}$=5.82 μm). Compatible findings were also obtained by others (İlter *et al.* 2002; İlter and Balkız 2005; Burdurlu *et al.* 2006) (Table 5).

**Table 4.** Statistical Values for $R_a$ According to Cutting Direction

| Direction | Number of Samples | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Radial | 90 | 5.82 | 0.074 | 5.67 | 5.96 |
| Tangential | 90 | 5.40 | 0.074 | 5.26 | 5.55 |

The surfaces obtained in tangential cuts were found to be smoother compared to the surfaces obtained in radial cuts. This could be caused by an increase or decrease in the tissue voids stemming from the fiber cutting angle together with the cutting method.

## Evaluation of the Data Obtained for $R_y$ ($R_{max}$) (Maximum Roughness)

The variance analysis calculated for $R_y$ from surface roughness parameters is given in Table 6.

**Table 5.** $R_a$ values of Wood Types

| Wood Types | Cutting Direction | Machine | | |
|---|---|---|---|---|
| | | Thickness 2 Blade | Thickness 3 Blade | Sanding No. |
| | | 10 m/min | 10 m/min | 80 |
| ***Eucalyptus camelduensis* Dehn.** (İlter and Balkız 2005) | Radial | 5.839 | 5.496 | 6.733 |
| | Tangential | 5.429 | 4.971 | 6.672 |
| **Bornmullerian Fir** (İlter *et al.* 2002) | Radial | 3.885 | 4.551 | 8.410 |
| | Tangential | 4.073 | 4.084 | 7.816 |
| ***Pinus brutia* Ten.** (Burdurlu *et al.* 2006) | ***Circular Saw*** | | - | - |
| | Radial | 6.770 | 5.550 | 5.740 |
| | Tangential | 6.640 | 4.480 | 5.320 |

**Table 6.** Variance Analysis for $R_y$

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Squares | F | P |
|---|---|---|---|---|---|
| Machine(A) | 6836.138 | 2 | 3418.069 | 5963.635 | 0.00* |
| Cutting Direction (B) | 201.105 | 1 | 201.105 | 8.663 | 0.00* |
| A*B | 887.835 | 2 | 443.917 | 8.085 | 0.00* |
| Error | 9553.547 | 174 | 54.905 | | |
| Total | 344914.600 | 180 | | | |
| ns=(not significant) *=<0.05 important | | | | | |

According to the results listed in Table 6, not only do the machine type and cutting direction affect $R_y$ values, but also the dual effects of these variables on $R_y$ are statistically important. According to the results of the Tukey's test performed to compare the averages, the smoothest surfaces were obtained with the thickness machine ($R_y$=35.57 μm), followed by the sanding machine ($R_y$=41.78 μm) and the circular saw ($R_y$=50.59 μm) (Table 7).

**Table 7.** Tukey's Test Results for $R_y$ According to Machine Type

| Machine | N | α=0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Thickness | 60 | 35.57 | | |
| Sanding | 60 | | 41.78 | |
| Circular | 60 | | | 50.59 |

When statistical values according to cutting direction (Table 8) were investigated, the average maximum profile height values of the samples cut tangentially were lower than those of the samples cut radially ($R_{yTangential}$=41.594 µm, $R_{yRadial}$=43.708 µm).

**Table 8.** Statistical Values for $R_y$ According to Cutting Direction

| Direction | Number of Samples | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Radial | 90 | 43.708 | 0.781 | 42.166 | 45.249 |
| Tangential | 90 | 41.594 | 0.781 | 40.052 | 43.135 |

$R_y$ results values found in this work were similar to those determined in previous studies (İlter and Balkız 2005; İlter *et al*. 2002).

## Evaluation of the Data Obtained for $R_z$ (Mean Peak-to-valley Height)

The variance analysis calculated for $R_z$ surface roughness parameter is given in Table 9.

**Table 9.** Variance Analysis for $R_z$

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Squares | F | P |
|---|---|---|---|---|---|
| Machine(A) | 5017.119 | 2 | 2508.560 | 137.131 | 0.00* |
| Cutting Direction (B) | 324.496 | 1 | 324.496 | 17.131 | 0.00* |
| A*B | 272.345 | 2 | 136.172 | 7.444 | 0.00* |
| Error | 3183.001 | 174 | 18.293 | | |
| Total | 207989.700 | 180 | | | |
| ns=(not significant)<br>*=0.05 important | | | | | |

According to the results listed in Table 9, not only the machine type and cutting direction affect $R_z$ values, but the dual effects of these variables on $R_z$ is statistically important. According to the results of the Tukey's test performed to compare the averages, the smoothest surfaces were obtained with the thickness machine ($R_z$=28.54 µm), followed by the sanding machine ($R_z$=30.62 µm) and the circular saw ($R_z$=40.63 µm) (Table 10). When statistical values according to cutting direction (Table 11) were investigated, the average ten-point height values of the samples cut tangentially were lower than the samples cut radially ($R_{zTangential}$=31.923 µm, $R_{zRadial}$=34.609 µm).

**Table 10.** Tukey's Test for Different Machine Types

| Machine | N | α=0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Thickness | 60 | 28.54 | | |
| Sanding | 60 | | 30.62 | |
| Circular | 60 | | | 40.63 |

**Table 11.** Statistical Values for $R_z$ According to Cutting Direction

| Direction | Number of Samples | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Radial | 90 | 34.609 | 0.451 | 33.719 | 35.498 |
| Tangential | 90 | 31.923 | 0.451 | 31.034 | 32.813 |

$R_z$ results values found in this work were similar to those determined in a previous studies (İlter and Balkız 2005; İlter *et al.* 2002).

## CONCLUSIONS

1. In this work, the effect of various machining methods of *Pinus nigra* Arnold wood on its surface roughness characteristics was investigated. In light of preliminary results of this work, a stylus method can accurately be used to evaluate surface roughness of machined samples of black pine.
2. Specimens were processed with the following frequently-used surface treatment techniques: sawing with a circular saw, planing with a thickness machine, and sanding with a sanding machine (No. 80 sandpaper). After the samples were treated radially and tangentially with machines, their surface roughness values ($R_a$, $R_y$, and $R_z$) were measured. When the statistics of surface roughness values were examined (for $R_a$, $R_y$, and $R_z$), it was determined that the smoothest surfaces were obtained from samples treated with a thickness machine.
3. The roughness values of tangentially-cut surfaces were found to be the lowest, according to the previously mentioned statistical values.
4. Surface roughness is important for lowering the amount of surface material used in the wood industry, as well as for improving the adhesion process. Therefore, there are great benefits to determining the surface roughness values of tree species grown in Turkey.

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