# Investigation of the Effect of Machining Parameters on Surface Quality in Bamboo

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**Abstract:** The purpose of the study is to obtain optimum processing conditions by investigating the effect of machining parameters of bamboo (*Bambusa*) material on surface quality. Evaluation was performed for four machining parameters (cutters type, spindle speed, feed rate and depth of cut) and their effects on surface roughness. According to obtained data, roughness values increased with increasing machining depth. Increase in roughness values between 8000 rpm and 10000 rpm, decrease in roughness values between 10000 rpm and 14000 rpm, and increase in roughness values between 14000 rpm and 16000 rpm was observed. Roughness value increased with increasing cutter feed speed. Roughness value decreased by increasing number of blades in cutter in cutter type. The lowest roughness value was obtained at a machining depth of 2 mm at a spindle speed of 14000 rpm, a feed rate of 1000 mm/min and a cutter type 3 (four flute spiral end mill).

**Keywords:** bamboo; machining; surface roughness; wood

## 1 INTRODUCTION

Using wood material for construction purposes has been widely applied for ages. Because of its incomplete supply of wood and escalating environmental awakening for consumers and producers, wood products machining has recently become important. Consequently, optimization of machining process is studied. Current optimization is focused on chip formation, tool wear, wood surface quality, etc. In order to specify economical cost of end product, wood finishing is a substantial parameter. Therefore, surface roughness is used as descriptive feature to evaluate the success of wood finish. Different techniques have been used to measure surface roughness in the area of woodworking. Lumber surface roughness can be used to measure with an airflow method [1]. It is assumed that surface roughness in industrial practices can be handily measured with a light-sectioning shadow scanner method [2]. The stylus technique is commonly used to quantify surface roughness of wood. [3, 4]. Stylus, image analyses were preferred in past studies to qualify the surface quality of solid wood and wood based materials. The stylus tecnique is a mostlly used one in laboratories.

CNC woodworking machineries have been considerably used in the wood and furniture industries. Grooving, milling, and patterning of furniture materials are some usage areas of CNC. This kind of technology offers many benefits with respect to output and surface quality. In was reported that surface roughness increases with worn cutters [5]. Roughness of solid wood using in the woodworking and furniture industries has been investigated. Ilter at all. (2012) reported a study on surface roughness in planing and sanding of Uludag fir [6]. Surface roughness measurements in planing wood materials performed on black locust and walnut was reported by Efe and Gurleyen (2003) [7]. Malkocoglu (2007) investigated surface roughness of oriental beech, Anatolian chestnut, black alder, Scots pine and oriental spruce [8]. Evaluation on surface roughness in composite panels in addition to ten different wood materials was performed by Zhang and Jun (2007) [9]. Škaljić at all. (2009) obtained surface roughness values of planed beech, oak and fir specimens [10]. Sofuoglu (2008) investigated surface quality of larch, poplar, oak and cedar in planing process in various conditions [11]. Hernández and Cool (2008) performed face milling and helical planing in opposite and parallel directions to the fibers on surface of Canada birch wood in various working conditions. They reported that cutting depth had no effect on surface quality and feed rate had an effect on the adhesion resistance and surface smoothness [12]. The effect of machining parameters (feed rate, spindle speed, lateral step and depth of cut) used in CNC milling on MDF sheets was found to have an effect on surface quality [13]. A decrease in surface roughness by increasing speed, and an increase by increasing offset amount, feed speed, and cutting depth in CNC machining of MDF were reported in 14]. In birch wood species, it was observed that feed rate and speed had little effect on surface roughness. It was observed that both feed rate and rotational speed affected *Ra* in ash tree species, while changes in rotational speed of beech were effective on *Ra* [15]. Zhong and Hiziroglu (2013) used particle board used in furniture industry in Singapore, MDF, plywood, needle scanning method for 10 different wood species, and 3D image analyzer. They stated that both methods can be used successfully in furniture production [16]. In the study performed by Sofuogluand Kurtoglu (2015), average roughness values from the highest to the lowest in perpendicular and parallel direction fibers were measured as Lebanon Cedar, black pine, and black poplar, respectively [17]. Optimum point offset machining strategy for CNC machining of massive panel samples produced from Larix was achieved while feed rate was 1000 mm/min at 16000 rpm [18]. The lowest roughness values in massive panel material produced from scotch pine were obtained with cutter 1, raster machining strategy, 16000 rpm, 1000 mm/min feed rate and 4 mm depth [19]. Bendikiene and Keturak (2016) obtained roughness values parallel to fibers in birch tree compared to roughness measurements perpendicular to fibers. They suggested a low feed rate for good surface quality [20]. According to results obtained by laser and needle scanning method in beech tree and Ayous tree species, the lowest roughness value was obtained at 2 m/min feed rate at 18000 rpm [21]. In the study performed by Bal (2018), as feed rate and blade pitch increased, surface roughness increased, and machining time decreased according to data obtained in medium density fiber board in CNC machining. It was determined that blade pitch was more effective on surface roughness and machining time than feed rate. In milling,

cutting speed and feed rate affect roughness. In sanding, sanding particle size was found to be important in surface roughness [22]. Surface roughness was reported as more important in machining perpendicular to fibers [23]. Sedlecký and etc. (2018) studied surface roughness in milling edges using medium density fiberboard (MDF), one side laminated medium density fiberboard and massive spruce panel. More accurate results in measurements were obtained with a non-contact profilometer, but it was long lasting and higher in terms of cost. The best results in terms of surface quality were achieved by reducing feed rate and increasing cutting speed [24]. Isleyen and Karamanoglu (2019) machined medium density fiberboard (MDF) with CNC in experiments. The effect of axial intersection depth was not statistically significant. A decrease in surface roughness by increasing speed and decreasing feed rate, and an increase in surface roughness by increasing cutter diameter were reported [25]. In machining of massive wood material using modern technology, it is important to determine optimal machining parameters for each wood species using controllable parameters. Bamboo is often used in furniture and interior decoration. Therefore, scopes of this study were organized as the following.

1. Choosing optimum machining parameters (depth of cut, spindle speed, cutter type and feed rate) for *Bambusa* material.

2. For the machined surface, stylus tracing surface roughness profilometer was used to measure surface roughness (*Ra*) values and statistical software (Minitab) was used to analyze the results.

## 2 MATERIAL AND METHODS

In this study, experiments were carried out by using a Bamboo (*Bambusa*) wood material that had 7 mm thickness. Wooden material had a density of 0.607 g/cm$^3$ at 12% moisture content ISO 13061-1, ISO 13061-2. Machining of materials was performed with a Scilled CNC machine (Beysantas A.S, Turkey). The experiments were done with four router cutters (Double flute flat end mill, *Z* = 2 Double flute spiral end mill, *Z* = 3 Three flute spiral end mill, *Z* = 4 Four flute spiral end mill was 8 mm in diameter) (Fig. 1). New and sharp cutters were used in each cutting test. Four machining parameters were used in the experiment and two of them had 3 levels, one of them 2 levels and the other had five levels (Tab. 1).
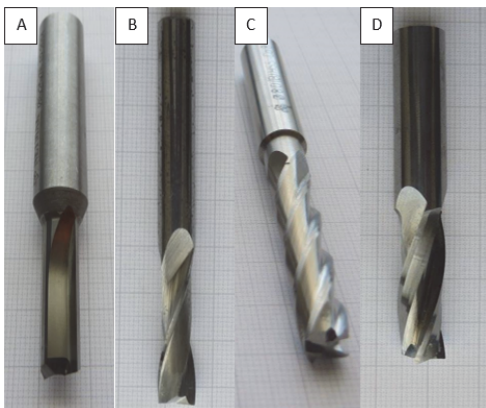


**Figure 1** Cemented carpide end mills A - (*Z* = 2 Double flute flat end mill, (Netmak) B - *Z* = 2 Double flute spiral end mill (Bup) C - *Z* = 3 Three flute spiral end mill (Bup), D - *Z* = 4 Four flute spiral end mill (MakineTakimEndustri A.Ş.).

A CNC router was used to groove 90 pieces of dimension 50 × 50 mm$^2$ in total (with raster machining strategy) on panels (Fig. 2a, Fig. 3). Surface roughness measurements were performed in the surface that was to grain at 5 different points for every sample. The measuring parameter (*Ra*) are described in ISO 468 (2009). The standards in ISO 4287 (1997), ISO 3274 (2005) and, ISO 468 (2009) were used to conduct surface roughness measurements. Determination of surface roughness values (Fig. 2b) was performed with Time TR200 (Time Group Inc., China) stylus type profilometer. The pick-up had a 2.5 mm of tallness; tracing tallness had a $L_t$ = 12.5 mm. Measuring speed, pin diameter and pin top angle of the tool were 10 mm/min, 4 μm and 90°, respectively. The temperature of measurement environment was adjusted around 18 - 22°C, and there were no vibrations. Calibration process of the tool were performed before measurement, and specified intervals were used to control calibration.

**Table 1** Levels designationfor factors

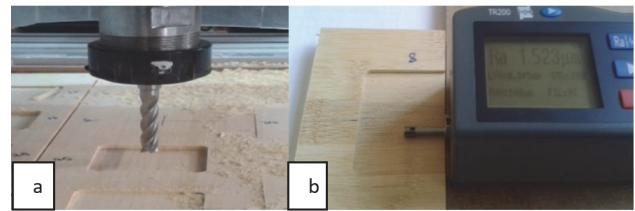| Machining parameters | Levels | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Cutter type | Cutter 1 (A) | Cutter 2 (B) | Cutter 3 (D) | | |
| Spindle speed / rpm | 8000 | 10000 | 12000 | 14000 | 16000 |
| Feed rate / mm/min | 1000 | 1500 | 2000 | | |
| Depth of cut / mm | 2 | 4 | | | |



**Figure 2**a).CNC milling machine (Scilled CNC) b) Surface roughness tester (Time *TR* - 200).
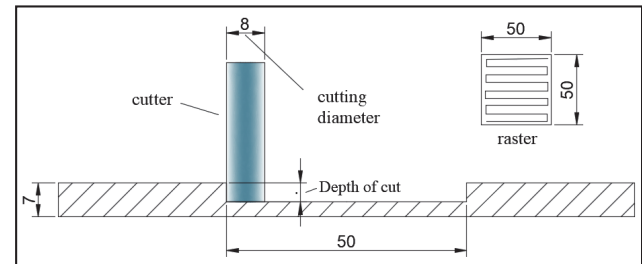


**Figure 3** Parameters of CNC process

As a result of machining process, machining with Z = 3 group spiral end mill was not included in evaluation because of burning and many fiber breaks occurred on surface and excessive rough and defective surfaces are obtained and problems in measuring roughness of surfaces by needle scanning method.

In the evaluation of results, ANOVA (Analysis of variance), and Tukey test were employed.

## 3 RESULTS AND DISCUSSION

Experiments were conducted to determine the effect of machining depth, speed, feed rate and cutter type on Ra and evaluated by using statistical methods in the study. Statistical results obtained from the findings are given below.

According to one-way analysis of variance test applied when the effect of machining depth on *Ra* value was investigated, *P* value was obtained as 0,299, according to this, it was seen that there was no statistically significant difference between groups in 95% confidence level (Tab. 2).

**Table 2** One-way ANOVA for the effect of machining depth on *Ra*

| Source | Degrees of freedom | Sum of squares | Mean square | *F* (test value) | *P* |
|---|---|---|---|---|---|
| Depth of cut / mm | 1 | 0,4507 | 0,451 | 1,09 | 0,299 |
| Error | 88 | 36,3456 | 0,413 | | |
| Total | 89 | 36,7963 | | | |

According to one-way analysis of variance test applied to examine the effect of speed on *Ra*, *P* value was found to be 0,607 at 95% confidence level, and according to this, there was no statistically significant difference between groups at 95% confidence level (Tab. 3).

**Table 3** One-way analysis of variance for the effect of speed (rev/min) on *Ra*

| Source | Degrees of freedom | Sum of squares | Mean square | *F* (test value) | *P* |
|---|---|---|---|---|---|
| Spindle speed / rpm | 4 | 1,141 | 0,285 | 0,68 | 0,607 |
| Error | 85 | 35,655 | 0,4195 | | |
| Total | 89 | 36,796 | | | |

According to one-way analysis of variance test applied to investigate the effect of feed rate on *Ra*, *P* value was found as 0,011 at 95% confidence level, and there was no statistically significant difference between groups (Tab. 4).

**Table 4** One-way analysis of variance for the effect of feed rate on *Ra*

| Source | Degrees of freedom | Sum of squares | Mean square | *F* (test value) | *P* |
|---|---|---|---|---|---|
| Feed rate / mm/min | 2 | 3,647 | 1,8223 | 4,79 | 0,011 |
| Error | 87 | 33,157 | 0,3810 | | |
| Total | 89 | 36,796 | | | |

After the analysis of variance was significant, Tukey test was applied and according to the obtained data, it was seen that 1500 and 2000 mm/min machining were at same group with 1000 and 1500 mm/min at same group and same time in terms of feed rate at 95% confidence level. At the same time and 1000 and 1500 mm/min were at the same group in terms of feed rate at 95% confidence level.

Tukey test was performed because the analysis of variance was significant. The feed rate of 1500 mm/mincan be evaluated in the same group with both 1000 mm/min and 2000 mm/min feed rate (Tab. 5).

**Table 5** Tukey Test for the effect of feed rate (mm/min) on *Ra*

| Feed rate / mm/min | N | Mean | Group |
|---|---|---|---|
| 2000 | 30 | 2,880 | A |
| 1500 | 30 | 2,791 | A    B |
| 1000 | 30 | 2,4159 | B |

According to one-way analysis of variance test applied to examine the effect of cutter type on *Ra*, *P* value was found as 0,002, and according to this, there was statistically significant difference between groups at 95% confidence level (Tab. 6).

According to the data obtained from Tukey test performed as a result of the analysis of variance, it is seen that cutter number 1 forms a group and cutter number 2 and 3 together form a different group in terms of 95% confidence level. In other words, there is no significant difference in *Ra* surface roughness at 95% confidence level in machining with cutter 2 and 3 (Tab. 7).

**Table 6** One-way analysis of variance for the effect of cutter type on *Ra*

| Source | Degrees of freedom | Sum of squares | Mean square | *F* (test value) | *P* |
|---|---|---|---|---|---|
| Cutter type | 2 | 4,978 | 2,4889 | 6,81 | 0,002 |
| Error | 87 | 31,818 | 0,3657 | | |
| Total | 89 | 36,796 | | | |

**Table 7** Tukey test for the effect of cutter type on *Ra*

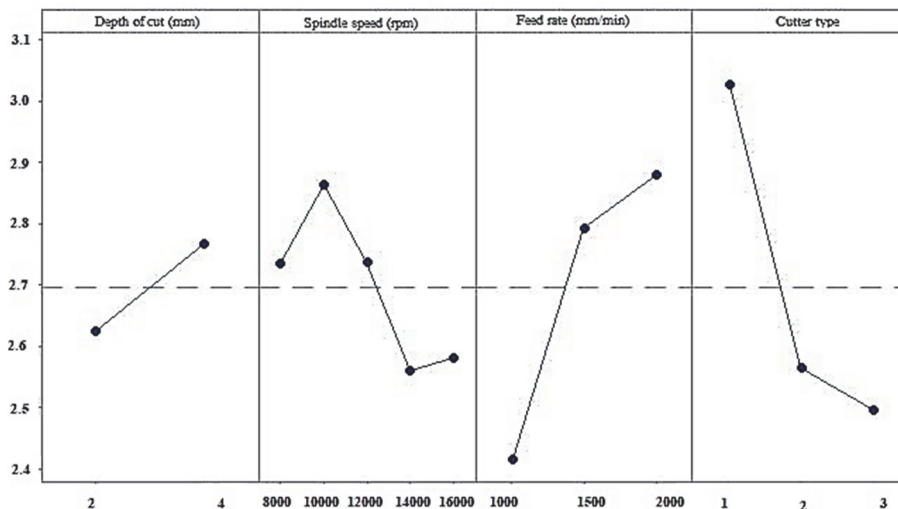| Cutter type | N | Mean | Group |
|---|---|---|---|
| 1 | 30 | 3,026 | A |
| 2 | 30 | 2,565 | B |
| 3 | 30 | 2,4962 | B |



**Figure 4** Interactions of machining depth, speed, feed rate, and cutter type in terms of *Ra*, main effect graph

According to *Ra* main effect graph, surface roughness increases as the depth of cut increases (Fig. 4). Non-deep cuts give smoother surfaces. Similar results were reported in other studies [14]. A remarkable stabilization was observed for depth of cuts at values 1 mm and 1.5 mm. It

is obtained that at higher cutting speeds, the *Ra* values decrease [26].

From the point of view of speed, increasing speed from 8000 rpm to 10000 rpm increased roughness and roughest surfaces occurred. However, with the further increase in speed (12000, 14000 rpm), a decrease in *Ra* occurred linearly. However, a small increase in roughness was achieved by increasing the speed to 16000 rpm. These unexpected increases or decreases in the linear course can be caused by vibrations in the CNC at some speed. It can be thought that this situation caused from this reason. When the effect of cutter feed rate on *Ra* is examined, a significant increase in *Ra* value was seen by increasing feed rate from 1000 mm/min to 1500 mm/min., and Ra value increased by increasing feed rate to 2000 mm/min, which is the maximum speed of CNC machine, but this increase was slightly lower.Similar results were reported in other studies. An increase in spindle speed and feed rate resulted in a decrease in surface roughness [10, 21, 22, 26-29]. The surface roughness of MDF increased with lower spindle speed, lower stepover, lower feed rate and lower depth of cut [14].

When the main effect graphs for *Ra* were examined in terms of the cutter type (Fig. 4), the lowest roughness values occurred at a machining depth of 2 mm, at a speed of 14000 rpm, a feed rate of 1000 mm/min and a cutter type 3. The highest *Ra* value (the worst surfaces) occurred at a machining depth of 4 mm, at a speed of 10000 rpm, a feed rate of 2000 rpm and a cutter type 1.

When cutters are evaluated in terms of surface roughness, the best surface to the roughest surface is 3 (D = Four-flute spiral end mill), 2 (B = Double flute spiral end mill), 1 (A = Double flute flat end mill) cutters, respectively.
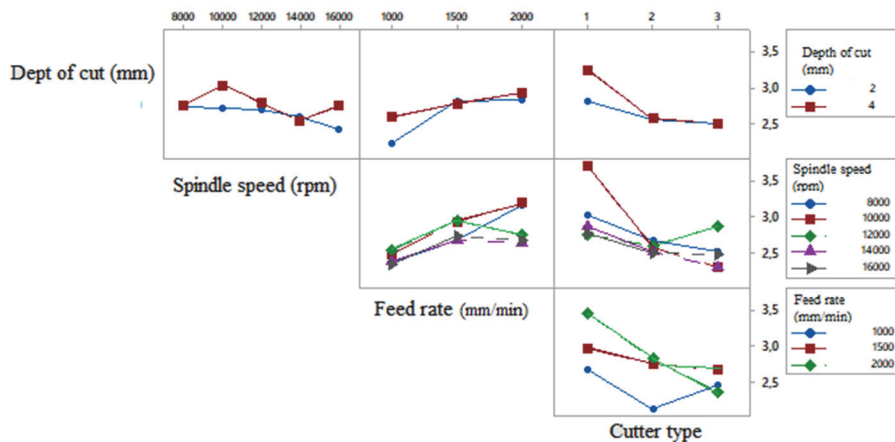


**Figure 5** Interactions of machining depth, speed, feed rate, and cutter type in terms of *Ra*

In Fig. 5, interactions of machining depth, speed, feed rate and cutter type in terms of *Ra* are shown graphically. In all interactions, it is seen that cutter 1 gives rougher surfaces. Other factors vary, and different situations may occur depending on interacting factor.

## 4 CONCLUSION

The following results can be outlined from the Ra perspectives, on the basis of the experimental results obtained for the made of Bamboo (*Bambusaa*):

- It was seen increase in surface roughness by increasing machining depth.
- Increase in cutter speed improves to a certain degree of roughness, and more increase creates rough surfaces.
- An increase in feed rate resulted in an increase in surface roughness (*Ra*), while an increase in spindle speed resulted in a decrease in surface roughness.
- ANOVA results indicated thattype of cutterwas the most dominantparameteraffecting surface roughness. Roughness values of machined surfaces decrease in case of increasing number of blades in cutter.
- Optimal cutting performance (minimum surface roughness) for *Ra* was obtained for Cutter 3, 14.000 rpm spindle speed, 1000 mm/min feed rate and 2 mm depth of the cut.

## Acknowledgment

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