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CHECK OF SURFACE ROUGHNESS AVERAGE OF WENGE & MAPLE MILLING SURFACES

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ABSTRACT

Working in a CNC machines is one of the most popular woodworking processes. Often is more suitable to use Subtractive Rapid Prototyping (SRP) machines than classic CNC machines. In the current study the surface roughness checked for two different wood kinds, wenge and maple. For each kind of wood six specimens milling in a 3-axis SRP machine and then the surface roughness average (Ra) defined. During milling process two different tools used. For roughing phase, a square end mill and then a ball end mill for finishing. For roughness check a portable linear roughness tester instrument used to define the Roughness Average (Ra) for each specimen. During the milling process the spindle speed and fed rate varies. The spindle speed starts from 1.100 mm/min until to 2.400mm/min and feed rates starts from 9.00 rpm to 15.000 rpm. According to the results the changes in machining parameters have significant effect to surface quality. Wenge is harder than maple wood and that play an important role to surface roughness. As cutting parameters improved roughness average (Ra) is less.

Key words: CAD/CAM, CNC Rapid Prototyping, Roughness Average (Ra).

INTRODUCTION

The growth rate of a product requires rapid changes and inexpensive process during the development stage. Make of a product prototype through rapid prototyping devices aims to reduce possible error and fast delivery of final products to the market. Creating of prototypes is a common process in a variety of industrial sectors products such as furniture, automotive industry, consumer products, packaging materials, etc (Babalis et al. 2013). The manufacturing of a prototype model is carried out in rapid prototyping devices which are divided into three categories: additive manufacturing technics, subtractive methods and casting technics.

The history of CNC machines starts in decade of 50’s, then the first 3-axis milling machine manufactured. Later in decades of 60’s and 70’s enormous development made until to have NC and later CNC machines (Seames 2002). Nowadays CNC machines are the basic production tools for all sectors of industrial production. The most common type of CNC are milling and lathe which are heavy duty and productivity machines. Over the last decades except typical machines are used smaller CNC machines. These CNC machines are called Subtractive Rapid Prototyping (SRP). In comparison with Additive Manufacturing machines SRP have the advantage to prototype in end use materials. Also models produced with SRP machines have better structural integrity than additive manufacturing models. Also, in subtractive prototyping it’s easily to have different surface finishes, from rough to completely smooth surface (Frank, M.C., et al. 2002). The first SRP machines are developed in decade of 80s. Usually are 3-axis or 4-axis machines. They are fully integrated with most of common CAD/CAM systems. Most of them are supported with owned software. In SPR machines specimens of steel, aluminum, plastic, wood, wax and brass can be machined. Compared with typical CNC machines SRP are much cheaper and dimensional accuracy can be at 0.025 mm.

Recently, more and more researchers, are study cutting process in CNC machines. The main reason of that is the optimization of the cutting parameters, and as a result, is the working time saving, the better cutting quality and the reduction of the electric energy consumption. Although, due to the machinery development, the manufacturing industries have reduced in a significant extent the electric energy consumption, however this remains in a high level and as a result affects the sustainability of a business (Tapoglou, 2016). The main criterion for the increasing of the machine's efficiency and the decreasing of the operating cost, is the cutting optimization that is considered the main – key factor for the profitability and the competitive advantage of a company (Kanakaraja, 2014).

In cutting parameters optimization, the goal is not only to reduce machining time but also a prerequisite is product quality to be increased. The product quality can be approved from surface roughness measurement. Most academic and industrial studies that have been carried out present results of optimization cutting in metallic specimens. However, there are not enough studies on the wood and wood products cutting parameters. Check of surface quality is a main outcome in similar research studies. The wood surface roughness is one of the main criteria that characterize the quality of the product. In order to specify the wooden surface quality different factors, have to take into account: the wood kind, the moisture in the wood, the wood density, the hardness of the wood, the annual ring change of the tree, the cell structure of the wood and the mechanical processing. The CNC machines have already been imported and took wide use in the wood - furniture industry since many wood treatments such as the profile creation, grooves and the surface design are made very easy and in a fast speed. The technology of the CNC machines offers advantages such as production speed, production cost decrease and better surface quality. Therefore, choosing optimization parameters in machining process, can significantly improve the cutting quality and provide better results on wood surface (Makris & Ntintakis, 2019). The mean arithmetic deviation of the roughness profile (Ra) was investigated for the edge surface after edge milling of medium-density fiberboard, medium-density fiberboard with single-sided lamination, and spruce edge-glued panel investigated in (Sedlecký, 2017). Other study presents analysis of relations between the instantaneous tool displacements and surface roughness formed during ball end milling of surface with inclination towards the tool's axis (Wojciechowski et.al, 2018). Other paper shows the influence of the relative position of the face mill towards the workpiece and milling kinematics on the components of the cutting forces, the acceleration of the machine spindle in the process of face milling (considering the rotation of the mill for a full revolution), and on the surface roughness obtained by face milling (Pimenov, et al, 2019). Also, the effect of the sharpness angle on the quality of machined surface of native wood species have been checked (Pinkowski, et al. 2018). Wilkowski et al. utilized Taguchi method to investigate effective factors for CNC processing parameters of wood surface roughness of oak and ash. Another study of Sütcü and Karagöz, 2012, analyzed the same

CNC processing parameters such as spindle speed, feed rate, stepover and depth of cut on surface roughness and material removal rate.

EXPERIMENTAL METHODS

In current study we check the quality of machining wooden surfaces in Subtractive Rapid Prototyping (SRP) machine. We choose to check two kinds of wood specimens. The first wood material is wenge and the second one is maple. Initially, a typical 3D model designed in a CAD system (Fig. 1). The specimen geometry consists from flat surfaces. The specimen dimensions are 80mm length, 60 mm width and 20 mm height. The whole depth of milling is 5mm. The upper surface is the milling surface where we will check roughness quality.

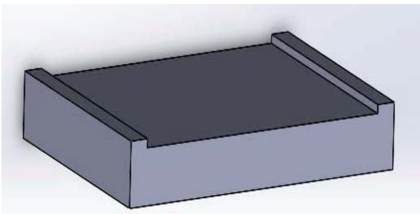

Figure 1: The wood specimen distances are 80x60x20 mm, the total cutting depth is 5 mm

After design completed a stl file format created in order the 3d model to recognized from the CNC software. Before each cutting process starts for each specimen the zero point in X, Y, Z axis set up. During the cutting tests the parameters which changed are: a) the kind of wood specimens, b) the selected cutting tool for roughing and finishing, c) the step depth, d) the feed rate and e) the spindle speed during roughing and finishing stage. All these parameters are checked with the cutting time and surface roughness quality.

The profile roughness parameters are included in BS EN ISO 4287:2000 British standard, identical with the ISO 4287:1997 standard (EN ISO 4287:2000). The standard is based on the ″M″ (mean line) system. In current study we check Roughness Average (Ra) parameter which is the most critical parameter. The surface roughness average (Ra) defined as the arithmetical mean of the deviations of the roughness profile from the central line (lm) along the measurement. The formula for the surface roughness average (Ra) is defined in Eq.1. (ArbizuI & Perez, 2003)

$$R_a = \frac{1}{l}\int_0^l |y(x)|\,dx \quad \textbf{(1)}$$

Where: y(x) is the profile value of the roughness profile and l is the evaluation length

WOOD SPICEMENS

For the species wenge, other common names are dikela, mibotu, bokonge, awong, nson-so, and palissandre du Congo. Its unique botanical name is Millettia laurentii and belongs to Leguminosae family. Its name was given by the Belgian botanist, Emile August Joseph De Wildeman. Generally, wenge is a very heavy wood (880 kg/m3), having a heartwood of dark brown color. Unique features for wenge are the thin black streaks with white parenchyma in between, a very beautiful and characteristic texture. Although the wood is almost straightforward, it can be difficult to work with hand or machine tools. Wenge has a faint, slightly bitter scent, when being worked. Markedly, wenge is one of the most durable wood species in the planet (ref. EN 350), very resistant to termites and sea microorganisms. As a forest tree species, it grows mainly in the rain forests of Democratic Republic of the Congo (former Zaire) and less in Cameroun and Gabon. In respect to its mechanical properties, wenge wood has a high resistance in bending (MOR), a high impact strength, and rather medium resistance in compression. The mean density of wenge wood (at 12% moisture, R12) is circa 0.88 g/cm^3.

Maple wood has several common names, like European maple, Norway maple, plain maple, soft maple, hard maple and other. It is not one species. Some main botanical names, for maple species, are Acer campestre, Acer platanoides (Norway maple), Acer saccharum (hard maple or sugar maple) and other, while its family name is Aceracea. In general, maple is a heavy wood (e.g., 690 kg/m^3 for plain maple and 660 kg/m^3 for European maple), with a remarkably high hardness in respect to its density. Maple has a cream white colour after cutting and some light brown. It has a natural luster in the radial section. It is straightforward, but often can have some corrugated or curly textures. Maple wood has a middle resistance in bending (MOR) and compression, with a medium modulus of elasticity (MOE). On the whole, the density of maple wood (at 12% moisture, R12) varies significantly, between 0.61–0.71 g/cm^3, depending upon the species type (hard maple, soft maple etc.), as well as the forest and climatic conditions [Tropix 7 2020], [The wood database 2020].

RESULTS AND DISCUSSION

The experiments are consists of twelve specimens, six of them are wenge wood and the other six of maple wood. All specimens are used in machining phases of roughing and finishing. In roughing phase, we use a Square end-mill High Speed Steel, with 6 mm diameter and 15 mm Flute length. And in finishing phase a Ball end-Mill High Speed Steel, with 2.5 mm radius and 20 mm Flute length. The second stage of the results is the measurement of roughness on the cutting surfaces after roughing and finishing process.

EXPERIMENTAL RESULTS OF CNC CUTTING PROCESS

In experimental tests cutting parameters in roughness phase are the same for the twelve specimens. Also cutting parameters are the same for all specimens in finishing phase. Tests starts with basic parameters as in Table 1. In the first test the whole process time is 24 minutes, spindle is 9.000 rpm, and feed rate is 1.100 mm/min.

Table 1: First experimental test results

Type of Process	Specimen Material	Depth [mm]	Feed Rate [mm/min]	Spindle [rpm]	Finish Margin [mm]	Cutting Amount [mm]	Machining Time [min]
Roughing	Wenge	10	1.100	9.000	0.10	0.72	24
Finishing	Maple	7.3	1.100	9.000	0	0.10	

In the second test total is reduced from 24 to 21 minutes. Feed rate and spindle have been increased to 1.300 and 11.000 respectively (Table 2).

Table 2: Second experimental test results

Type of Process	Specimen Material	Depth [mm]	Feed Rate [mm/min]	Spindle [rpm]	Finish Margin [mm]	Cutting Amount [mm]	Machining Time [min]
Roughing	Wenge	10	1.300	11.000	0.10	0.72	21
Finishing	Maple	7.3	1.300	11.000	0	0.10	

In the third test the feed rate increased to 1.500 and spindle to 12.000 rpm, the results are presented in Table 3.

Table 3: Third experimental test results

Type of Process	Specimen Material	Depth [mm]	Feed Rate [mm/min]	Spindle [rpm]	Finish Margin [mm]	Cutting Amount [mm]	Machining Time [min]
Roughing	Wenge	10	1.500	12.000	0.10	0.72	18
Finishing	Maple	7.3	1.500	12.000	0	0.10	

In fourth experiment we set the spindle in 15.000 rpm which is the highest value in Rolland MDX 40A CNC machine. Machining process completed in 13 minutes.

Table 4: Fourth experimental test results

Type of Process	Specimen Material	Depth [mm]	Feed Rate [mm/min]	Spindle [rpm]	Finish Margin [mm]	Cutting Amount [mm]	Machining Time [min]
Roughing	Wenge	10	1.800	15.000	0.10	0.72	13
Finishing	Maple	7.3	1.800	15.000	0	0.10	

In fifth machining test only the feed rate increased from 1.800 to 2.200 (mm/min), the machining time decreased two minutes (Table 5).

Table 5: Fifth experimental test results

Type of Process	Specimen Material	Depth [mm]	Feed Rate [mm/min]	Spindle [rpm]	Finish Margin [mm]	Cutting Amount [mm]	Machining Time [min]
Roughing	Wenge	10	2.200	15.000	0.10	0.72	11
Finishing	Maple	7.3	2.200	15.000	0	0.10	

In the last experimental test, the feed rate increased in the maximum value of 2.400 (mm/min) and the total machining time decreased one minute (Table 6).

Table 6: Sixth experimental test results

Type of Process	Specimen Material	Depth [mm]	Feed Rate [mm/min]	Spindle [rpm]	Finish Margin [mm]	Cutting Amount [mm]	Machining Time [min]
Roughing	Wenge	10	2.400	15.000	0.10	0.72	10
Finishing	Maple	7.3	2.400	15.000	0	0.10	

From the results turns out that the machining process can be executed in the maximum values of feed rate and spindle speed. In the second section of the results we are going to check the quality of the machining surfaces from both kinds of wood, measuring surface roughness.

EXPERIMENTAL RESULTS OF SURFACE ROUGHNESS

For roughness check we use a portable linear roughness tester instrument. Measuring results are printed to a special printer device (Fig. 2). Measurement process follows the same procedure for all specimens. In each specimen we make two different roughness tests. One test after roughing and one more after finishing. The main parameter we check in these tests is *Roughness average* (Ra). In

Table 7 are presented the results from surface roughness tests for each specimen and for each end mill cutting tool.

Figure 2: Roughness measurement with portable linear instrument

Table 7: Roughness test results for each machining surface

Machining test number	Type of Process	Specimen Material	Ra [μm]	End Mill Tool
1	Roughing	Wenge	3.956	ZHS-600
	Finishing		1.510	ZUB-250
	Roughing	Maple	2.575	ZHS-600
	Finishing		1.183	ZUB-250
2	Roughing	Wenge	7.980	ZHS-600
	Finishing		3.966	ZUB-250
	Roughing	Maple	3.771	ZHS-600
	Finishing		1.326	ZUB-250
3	Roughing	Wenge	6.797	ZHS-600
	Finishing		3.966	ZUB-250
	Roughing	Maple	3.616	ZHS-600
	Finishing		1.375	ZUB-250
4	Roughing	Wenge	4.366	ZHS-600
	Finishing		3.361	ZUB-250
	Roughing	Maple	2.140	ZHS-600
	Finishing		1.068	ZUB-250
5	Roughing	Wenge	4.682	ZHS-600
	Finishing		1.567	ZUB-250
	Roughing	Maple	2.156	ZHS-600
	Finishing		0.925	ZUB-250
6	Roughing	Wenge	2.494	ZHS-600
	Finishing		1.682	ZUB-250
	Roughing	Maple	1.099	ZHS-600
	Finishing		0.766	ZUB-250

According to above results the changes in machining parameters have significant effect to surface quality. Wenge wood is harder than maple wood and that play an important role to surface roughness. As cutting parameters improved than surface roughness is less. Machining time decreased from 24 minutes in first test to only 10 minutes in sixth test. For wenge specimen's Ra is lower except the spacemen after finishing stage in first test. This result maybe is random and be occurred from the high imbalance of wenge wood structure. For Maple specimens the lower Ra is in the sixth series. Another result about the type of different end mill. So, for flat surfaces it is not necessary to use the ball end mill tool in finishing, there are not major differences in surface roughness.

CONCLUSIONS

Wood machining will continue to have a major role in furniture industry. It is necessary to have the best product quality and same time to reduce machining time. In wood and furniture industry desktop CNC machines play a major role in production process. In recent years new mini or desktop router machine will be available. These devices should have the ability to machining high quality surfaces. Prototyping CNC devices are a good solution for the industries because they can produce high quality surfaces. One basic disadvantages of these devises is the lower dimension of stock. In this study we use the Rolland MDX 40A which is a four axis Subtractive Rapid Prototyping (SRP) device. For the tests we use the devise for 3-axis milling of flat surfaces of two different wood kinds, wenge and maple, and twelve specimens totally. A next stage for the future it would be to check the surface roughness in more complex surfaces of fourth axis milling in a subtractive rapid prototyping CNC machine.

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CONTENTS