Article

Wood filled plastics – machining and surface quality

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Abstract: Components made of wood plastic composites are used in exterior application, where in comparison with nature wood composite do not require further maintenance (predetermine to long-term usage for its physical and mechanical properties). Adding wood to plastic significantly increases mechanical properties (utmost stiffness), reduces thermal expansion of the plastic and decreases of cost. Design of product is not limited by material and technology and is possible to product different types of profile and shapes. Nowadays demand on wood plastic composites is with increasing character. For this reason, a better understanding of this composite material in regards to machining and texture of surface is necessary. The paper deals with a comparison of the surface roughness of Wood Plastic Composite with traditional wood (oak) after turning. Presented paper is focused on observation changes of average maximum height Rz with change of speed of feeds f and speed of rotations nc (simultaneously compare predicted and real values of surface roughness parameter Rz). Experiment was realized with monolithic cutting tool made of high speed steel (EN ISO HS6-5-2) with positive geometry. Machining of WPC was in direction parallel to extruding axe, and verification sample in parallel fiber direction. Graphical evaluation of experimental values was realized using software OriginLab. Detecting surface quality was made using microscopic camera DigiMicro 2.0.

Keywords: keyword 1; keyword 2; keyword 3 (List three to ten pertinent keywords specific to the article; yet reasonably common within the subject discipline.)

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1. Introduction

Terms wood plastic composite (then WPC) describe material formatted by join of two homogeneous substances – thermoplastic matrix reloaded with cellulose fibers (wood). The matrix utilized typically need to have melting temperature that is below the thermal decomposition of wood ~ 200 degrees C, in virgin or recycled form [1–3]. The wood used to manufacture of WPC is mostly in the form of wood flour (wooden milled grains from different kind of wood, e.g. maple, pine, oak, typically 40 mesh or lower) in high ratio 50 – 70 %. Additives to the composites will include processing aids and property modifiers. Adding wood to plastic significantly increases mechanical properties (utmost stiffness), reduces thermal expansion of the plastic and decreases of cost [4,5]. However problems with composite wood-plastic are compatibility between components and questions regarding the ability of natural organism to attack the wood fibers. WPC materials are used as adequate replacement for preservative treated wood and the more expensive durable wood species (such a teak)[6–9]. Design of product is not limited by material and technology and is possible to product different types of profile and shapes. Colour differences can be obtained by add pigments to achieve real look of natural wood or variable colour combinations. Increasing trends of usage WPC products aim technologist to use conventional technologies such as drilling, planning, milling and turning [10]. Knowledge about cutting processes is not detailed described as is described mentioned process in metal or plastic machining. Base on available information producer present statement, that composite material based on natural fibers are easy machinable with cutting tool intended for wood machining (describe by study D. Saloni, U. Beuhlmann,and R. L. Lemastre, which describe surfaces of WPC after milling and grinding). Result of experimental series is: ”Surface roughness after cutting WPC materials is similar to wood in comparison with pine sample”, but is necessary to aim an attention on cutting conditions of selected technology, geometry of the cutting tools and process environment [11]. Result of interaction of upper mentioned factors is obtained surface topography, which is depended on compatibility and mechanical properties of the components / products.

Figure 1. Components of WPC [1]

2. Experimental part

Experimental material was composite with high ratio of wood flour (70%) in combination with polyethylene matrix (dimension of extrude profile bxhxl: 40 x 60 x 3600 mm). Mechanical properties were set by laboratory VUHZ Ostrava Dobra. Material was cut to required shape of normalized dimension testing samples for tensile testing and three point bend test according to standard ISO 6892 respectively ISO 178 (5 samples from middle of profile in extruding direction). Tensile test was realized with constant load speed 0,015 mm.s-1. Result values after testing are shown in table follows. Final testing of experimental sample was remarked by destruction at load 200N (probably reason is defect occurrence), what is the reason of non-listed the values in the table. Three bend testing was realized with constant load velocity 0.08 mm.s-1 and results are also shown in table below. Verification sample was made of natural maple wood.

Table 1. Values of mechanical properties after tensile test and three point bending test.

Mechanical property	Values (tensile test)
Tensile strenght [MPa]	24/ 15/ 24/ 15/ * defect
Engineering strain [%]	2.8/ 2.9/ 3.4/ 5.1/ * defect
Contracity [%]	2.0/ 0.4/ 0.8/ 0.4/ * defect
Deformation work [mJ]	20.4/ 12.4/ 24.1/ 13.5/ * defect
Mechanical property	**Values (three point bending test)**
Flexual strenght [MPa]	18.76/ 15.69/ 16.71/ 15.44/ 17.13
Deformation work [mJ]	1.01/ 0.92/ 0.90/ 0.80/ 0.92

Turning was realized with monolithic cutting tool made of high speed steel (EN ISO HS6-5-2) with positive geometry with tip radius rε=5 mm. Process of turning was characterized by two variable parameters – feed rate per revolution from the range 0.1 to 0.61 mm and spindle speed nc=450 – 1400 min-1 (marking of the sample by selected combination variables – Table 2). Cutting was realized without using process fluids (without lubrication / cooling to avoid grain expansion the volume of machined materials). Machining of WPC was in direction parallel to extruding axe, and verification sample in parallel fiber direction. Sequence of final operation to prepare samples with required dimension was done by following steps (verification sample was deliver in round bar – steps 1 and 2 are skipped):

1. Cutting by frame saw → samples length 150 mm,
2. Cutting by frame saw → samples with square crosssection 40x40mm,
3. Turning → to diameter Ø36 mm, applied fixtures – three jaws chuck, tailstock quill
4. Final turning to required dimension at depth of cut ap=2,5 with tool geometry described above.

Table 2. Conditions of cutting process – WPC – Wood Plastic Composite , W – wood compared samples (spindle speed – n_c, feed rate – f)

No of samples	n_c [rpm]	f[mm.rev^{-1}]	No of samples	n_c [rpm]	f[mm.rev^{-1}]	No of samples	n_c [rpm]	f[mm.rev^{-1}]
WPC1 (W1)	450	0.1	WPC4 (W4)	900	0.1	WPC7 (W7)	1400	0.1
WPC2 (W2)	450	0.3	WPC5 (W5)	900	0.3	WPC8 (W8)	1400	0.3
WPC3 (W3)	450	0.61	WPC6 (W6)	900	0.61	WPC9 (W9)	1400	0.61

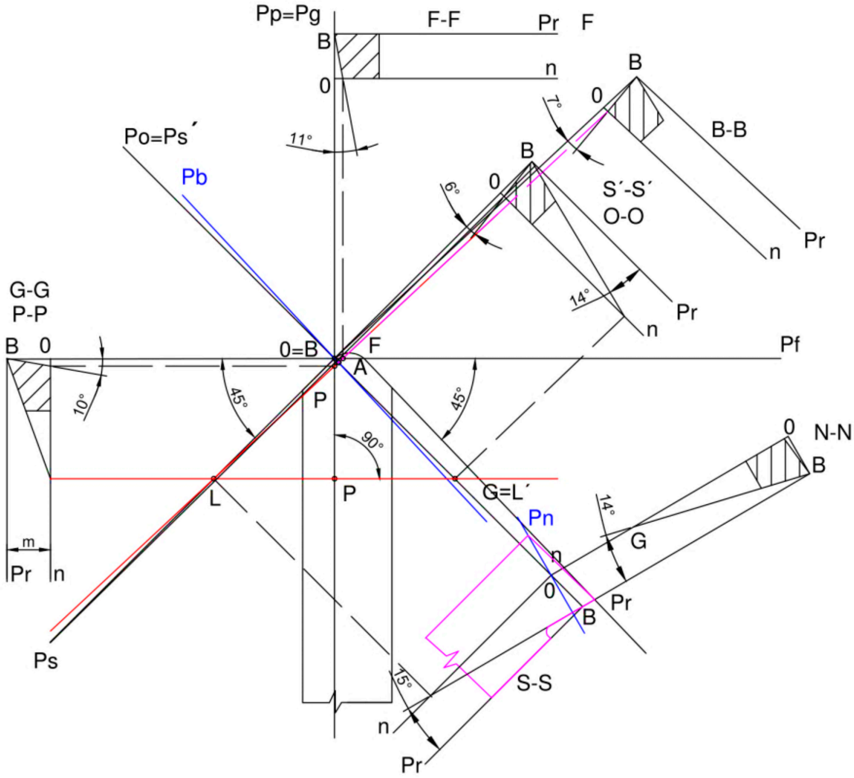
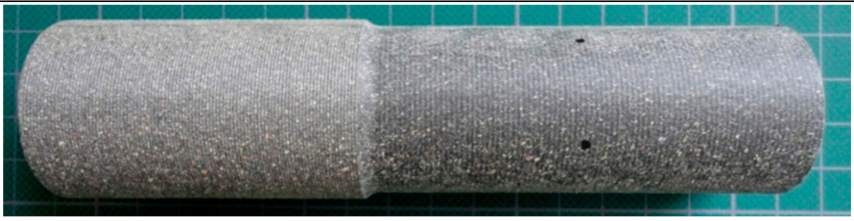


Figure 2. Geometry of applied turning tool

Qualitative evaluation of surface roughness parameters (Rz – maximal height of the profile, Ra – arithmetic deviation of the profile) was realized by standard STN EN ISO 4287. Measurement was realized with roughness meter MITUTOYO SJ-400 with measuring length lr=4 mm and using filter λc=0.8 mm (λs=2.5μm). Roughness was measured in three independent areas (marked 1. place, 2. place and 3. place) with repeatability 15 times. In the case of WPC samples the measurement was realized out of quadrate I. from the reason of anomaly formation on machined surface (Table 3). Measuring in first quadrant was real risk of tip damage.

Table 3. Define quadrant I. ad quadrant II. for WPC

Abnormality on the surface after machining (quadrant excluded from the measurement marked I.)



Ralized measuring on surface sample in quadrant II. (selcted areas with repeatibility 15 times in each places)

3. Results and discussion

Statistical confirmation of extreme deviation was evaluated by Grubbs test with accuracy 0.05 (exclusion of values overcast with gross error). Subsequently was calculated arithmetical averages in individual areas and evaluated summary arithmetical average (as average of average in three areas – shown in Table 4). Graphical evaluation of experimental values was realized using software OriginLab. Detecting surface quality was made using microscopic camera DigiMicro 2.0 (two axes lens) with transistor CMOS image sensor technology and software for precision measuring of distance between surfaces with accuracy 0.1 μm.

Table 4. Conditions of cutting process – WPC – Wood Plastic Composite , W – wood compared samples (spindle speed – n_c, feed rate – f)

	Wood Plastic Composite			**Comparative sample (Wood)**		
f [mm.rev^{-1}]	n_c=450 rpm	n_c=900 rpm	n_c=1400 rpm	n_c=450 rpm	n_c=900 rpm	n_c=1400 rpm
0.1	17.68 (WPC1)	14.57 (WPC4)	12.25 (WPC7)	12.17 (W1)	12.48 (W4)	12.22 (W7)
0.3	27.54 (WPC2)	20.48 (WPC5)	25.28 (WPC8)	11.82(W2)	13.91 (W5)	9.48 (W8)
0.61	33.06 (WPC3)	26.91 (WPC6)	25.96 (WPC9)	19.54 (W3)	18.99 (W6)	20.17 (W9)

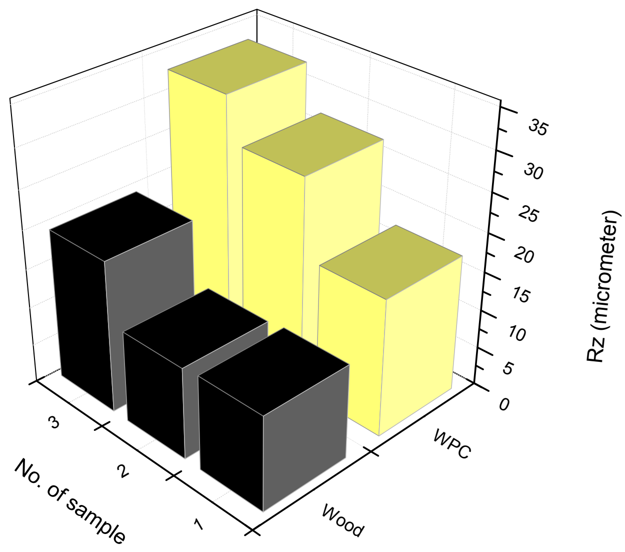


Figure 3. Histogram of measured values Rz at spindle speed 450 rpm for WPC and verification sample

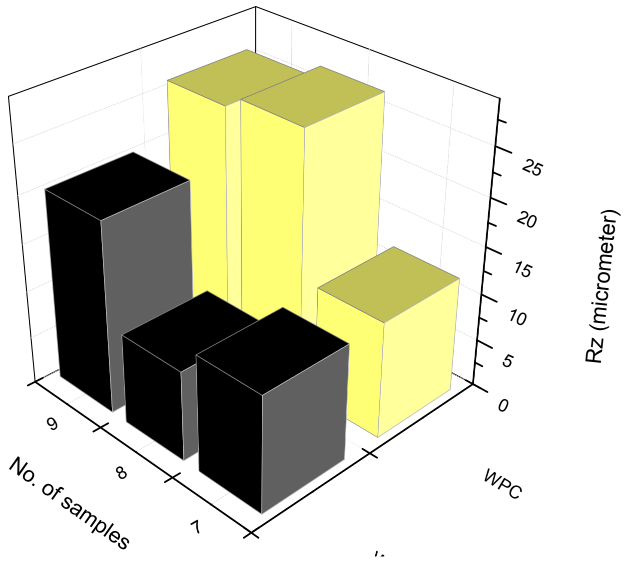


Figure 4. Histogram of measured values Rz at spindle speed 1400 rpm for WPC and verification sample

Values of surface roughness parameter Rz is shown in Table 4 at variable feed rate f and spindle speed nc. Machining of WPC confirm initial hypothesis, that surface roughness Rz increase in experimental range of spindle speed (450 – 1400 rpm). In the case of machining verification sample mentioned phenomenon was monitored is valid only for spindle speed nc=900 rpm. Minimal and maximal values of spindle speed acquire surface roughness decrease on lower level at feed rate per revolution 0.3 mm and subsequently at feed rate per revolution 0.61 mm again increase (in table samples marked W1 to W3 respectively W7 to W9). Constructed histograms point on differences in surface roughness values Rz at maximal and minimal spindle speed (Fig. 3, Fig. 4) for composite and wooden sample. Higher values of surface roughness parameter Rz was monitored at composite sample wood plastic at spindle speed 450 rpm (Fig. 3), where is maximal difference at feed rate pre revolution 0.3 mm (No. of samples – WPC2-W2 – distinction is 15.72 μm), at spindle speed 1450 rpm is described occasion similar. Difference is 17.85 μm at samples WPC8-W8 (feed rate per revolution 0.3 mm). Monitoring three independent places on the surface from the sight of surface quality and parameter Rz can be stated, that was acquired differences, where significant changes are described in figure follows (Fig. 5). Sample WPC5 was measured in three independent areas, where maximal deviation was determinate to 7 μm.

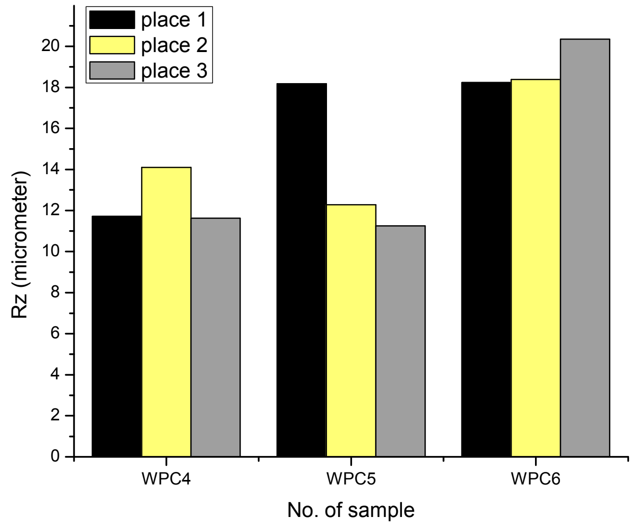


Figure 5. Sample WPC5 – maximal difference among measured values Rz (measuring in three independence surface areas) for cutting conditions feed rate per revolution 0.3mm and spindle speed 450 rpm

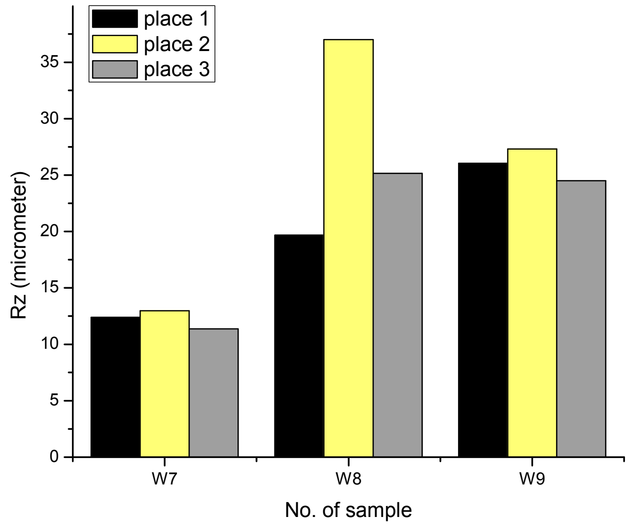


Figure 6. Verification sample W8 – maximal differences among measured values Rz (measuring three independent surface areas) for cutting parameters – feed rate per revolution 0.3 mm and spindle speed 1400 rpm

Constructed histogram (Fig. 6) describe differences in values of surface roughness parameter Rz after machining of verification wooden sample and result evaluation is statement about difference 17.34 μm between areas 1 and 2 of the sample W8.

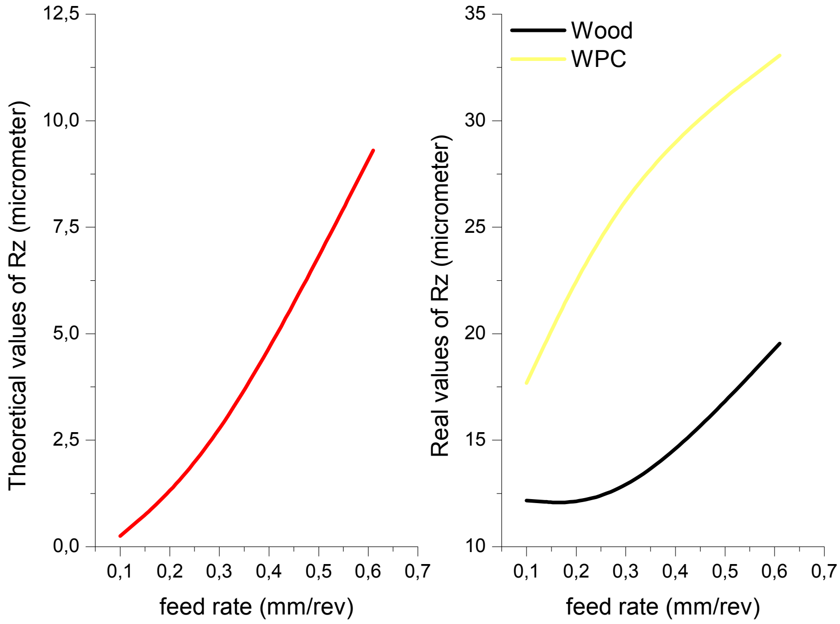


Figure 7. Dependence of parameter Rz on feed rate, - left theoretical course, and right – real course of values Rz for WPC and verification samples (used B-Spline function)

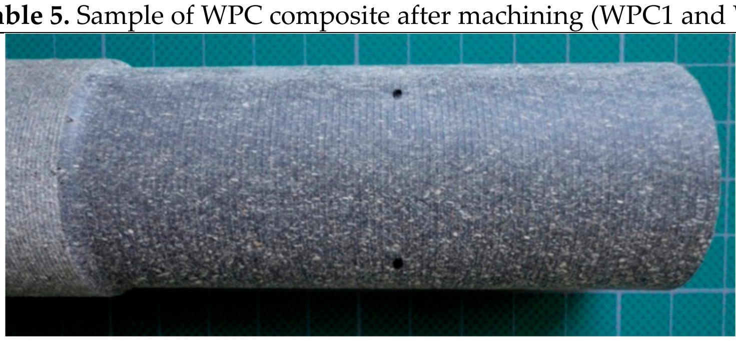
Maximum height of the surface roughness was conditioned by tip radius and feed rate base on mathematical equation:

$$Rz = \frac{f^2}{8 \cdot r_\varepsilon} \cdot 1000\ [\mu m] \qquad (1)$$

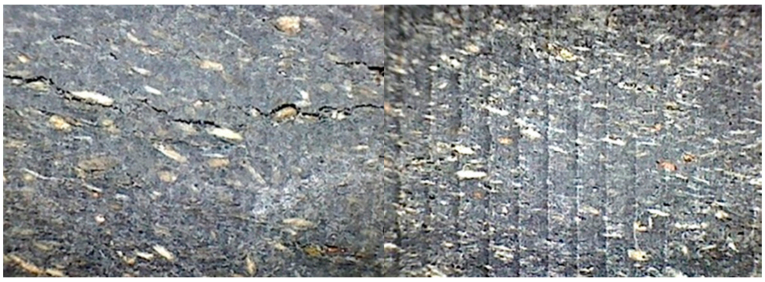
Surface machined with a tool with one cutting edge acquire shape prescribe by tool moving on the component surface. Wide different between theoretical and real values of surface roughness Rz were monitored at middle feed rates per revolution 0.3 mm at WPC sample (difference is 25 μm). Despite differences between real measured values and expected values of surface roughness the course of measured values of surface roughness Rz displays increasing character (Fig. 7).

Machining occur cracks on the surface areas on the WPC composite in axes of tool rotation during machining of components (in this case was necessary to cut samples into two quadrants (I. and II.). Machining with high feed rate and with at low cutting speed occurs trails after tool (see sample WPC 3 – machining at feed rate 0.61mm and spindle speed 450 rpm) where in comparison with verification sample trails are not monitored on surface. Reason of occurrence cracks on the surface are not caused by cutting conditions, but just individual composition and technology of producing composite material. Cracks on forehead of extruded profile were seen before machining and are cumulated into center of the sample – Table 5.

Table 5. Sample of WPC composite after machining (WPC1 and WPC 3)



Surface of the sample WPC 3 after machining (mark of quadrant II.)



Cracks on the sample surface WPC1 (quadrant I.), tool marks on the sample WPC3

4. Conclusions

Quality of surface after machining is theoretically directly dependent on combination of tool tip radius and feed rate (surface machined with tool with one cutting edge is prescribed by move of the tool tip on surface sample). Real values of micro geometric characteristic Rz are significantly higher than predicted (despite the fact that, for all three comparing courses is increasing tendency). WPC samples were cut in two quadrants before experimental measuring what cause differences in values of surface roughness parameter Rz and also variant material properties in various areas, which is resulting of inhomogeneity of the material. Confirm of statement is demonstrated by mechanical test – tensile test and three point bend test. Values of tensile strains are different of less than 10 MPa (differences between individual samples are shown in Table 1). Considering that experimental samples were cut from center of the extruded profile in direction of extruding can be state that differences on the edges of the profile would be differences in mechanical properties significantly differ. Wood plastic composite materials are machinable with cutting tools intended for wood materials with maintaining similar geometry.

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Jozef Zajac conceived and designed the experiments, František Botko poposed deign of tool and performed the experiments, Zuzana Hutyrová and Dusan Mitaľ analyzed data and wrote the paper and prepared samples, Marta Harničarová and Ján Valiček performed measurements, processed data and material testing.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

MDPI: Multidisciplinary Digital Publishing Institute
DOAJ: Directory of open access journals
TLA: Three letter acronym
LD: linear dichroism

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