Evaluation of Selected Parameters after Abrasive Water Jet Cutting of Wood Plastic Composite

Zuzana Mitaľová [1], František Botko [1], Juliána Litecká [2], Dušan Mitaľ [1]

[1]*Faculty of Manufacturing Technologies of Technical University of Kosice with seat in Presov, Sturova 31, 080 01 Presov, Slovakia*
[2]*Faculty of Humanities and Natural Science, Uiversity of Presov, 17. Novembra 3724/15, 080 01 Presov, Slovakia*

***Abstract* – Paper deals with cutting of composite material with natural reinforcement by AWJ (Abrasive Water Jet). The samples were cut with four different abrasive mass flow (from 150-300 g.min^{-1}) and different traverse speeds (depending on the required cut quality *Q* according standard list). SN 214001 standard is used for evaluating of one selected parameter – edge radius (r_k) by used a digital microscope. After the cutting, the weight loss/gain of the samples of the individual sets are also evaluated and conclusions formulated.**

***Keywords* – Composite Material, Abrasive Water Jet Edge Radius, Weight Loss.**

1. Introduction

The paper focus on the cutting by Abrasive Water Jet (AWJ) for composite material with natural reinforcement – Wood Plastic Composite (WPC). WPC present a material emerging from a fusion of two constituents – polymer matrix (for example polyethylene: PE / polypropylene: PP / polyvinylchloride: PVC / biopolymers, etc.) and wood flour (or fibers, volume more than 70 %) with additives (additives common in plastics processing, for example: coupling agents, UV protective agents, PVC heat stabilizers, flame retardants and smoke suppressants, biocides, density reduction additives, lubricants and pigments) [1], [2], [3]. These components (Figure 1) are mixed together and then pressed to different shapes. For linear decking profiles – extrusion, calendering, for 3D part – injection moulding. The limiting factor in the production process is the processing temperature, does not exceed 200 °C, at a higher temperature the wood component decomposes (some literatures state the temperature 220 °C) [2], [4].

WPCs offer resistance to biological deterioration agents / water / moisture / fungi attack (properties depends on the ration of components, characteristics of wood flour / fiber, type of additives, etc.) [5-9]. Can be substituted for solid wood in today's building structures and industrial applications if certain structural limitations are addressed. These materials have economic advantages because of variety in raw materials, as well as better natural durability in comparison with solid wood [10].

Applications of WPCs (Figure 2): buildings materials (integral door panel, wall panels, floors, cladding), outdoor facilities (fences, benches, floors, armrests), logistics facilities (pallets), furniture supplies (cabinets, tables, door frames), automotive industry (armrests, parts of seats, lining of car cabins), etc. [1], [2], [11], [12].

This material is environmental friendly, because no-added-formaldehyde in their formulations (possibilities to use a recycled plastics and products of the wood industry). Study Saeed Kazemi Najafi: „*Use of recycled plastics in wood plastic composites – A review*"points out the amount of plastic waste in European countries and the possibilities of their application, including the use of WPC products. Constantly increasing environmental pressure, new ways of using composite materials on a natural basis (including the mentioned WPC), as well as technical

DOI: 10.18421/TEM114-15
https://doi.org/10.18421/TEM114-15

Corresponding author: Zuzana Mitaľová,
Faculty of Manufacturing Technologies of Technical University of Kosice with seat in Presov, Slovakia.
Email: zuzana.mitalova@tuke.sk

Received: 12 July 2022.
Revised: 19 September 2022.
Accepted: 23 September 2022.
Published: 25 November 2022.

innovations lead manufacturers to their application (goal - reducing the consumption of financially demanding, non-recyclable types of reinforcements - e.g. glass fibers) [13].

Figure 1. Components of Wood Plastic Composite (wood flour / plastic matrix – PP / PE / PVC, additives) [14-16]

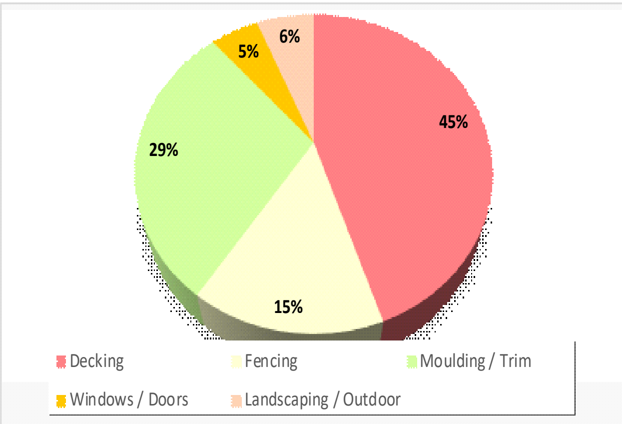

Figure 2. USA Wood Plastic Composite demand (2016, Plastic Information Europe) [17]

In many cases, it is necessary to apply conventional / unconventional machining technologies for their final application [18], [19]. One of the options is the application of AWJ cutting. Hydroabrasive water jet splitting is currently being reported as an alternative way of splitting materials. The principle of cutting consists in driving a hydroabrasive current into the cutting site. By applying the mixture to the cut material (up to a thickness of approx. 200 mm), it splits. The permeate, which carries the kinetic energy of the abrasive, washes away the removal products from the cutting site and ensures its cooling (high-speed AWJ is generated with the help of a hydraulic pump). The stream of water penetrating the workpiece gradually loses its kinetic energy and deviates (which results in the formation of irregularities – a groove, in the lower zone of the cut) [20], [21], [22].

The technology is suitable for cutting a wide range of materials (Cu, Al, composite materials, rubber, foam, polyurethane, mats, etc.). The advantage of AWJ division in the case of WPC materials (compared to conventional technologies, where interaction: tool versus material is necessary): elimination of melting of the plastic matrix and its gluing to the functional surfaces of the tool (Figure 3 – photos from a study dealing with the drilling of WPC materials, HDPE matrix glued in the groove of the coated drill) [23].

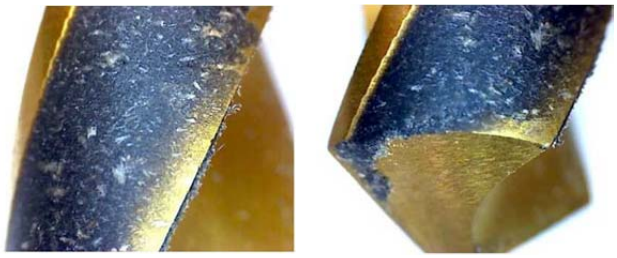

Figure 3. Detail of a TiN-coated high-speed steel drill after drilling (HDPE matrix adhered in the drill groove, drilled material: WPC) [23]

2. Experimental Procedure

Material: the experimental material was composite material with natural reinforcement (natural components certified by an organization PEFC – *Programme for the Endorsement of Forest Certification*) and HDPE matrix. Content of wooden filling – more than 75 % (density of extruded profile: 500-700 kg.m^{-3}). Use of extruded profile: carriers are not construction parts, but the supporting construction when assembling terraced boards (Figure 4).

Figure 4. Extruded WPC profile for AWJ cutting, thickness of material 40 mm (author´s archive)

Table 1. Marking of samples based on manufacturing conditions

	sample no. / m_a [kg.min^{-1}]	v_p [mm.min^{-1}]
Set A (required quality Q1)	1/150	346
	2/200	↓
	3/250	
	4/300	455
Set B, C, D	. . . .	↓
Set E (required quality Q5)	17/150	80
	18/200	↓
	19/250	
	20/300	105

Note: Setting the technological conditions for dividing samples of sets B, C, D: the technological parameter is in the interval 150-300 kg.min^{-1}, the technological parameter is determined by the AWJ device in relation to the required final quality of the cut (specified according to the standard).

Experiments were realized by means of an AWJ system (Water Jet 3015 RT-3D, Faculty of Manufacturing Technologies of Technical University of Kosice with seat in Presov), thickness of cut samples – 40 mm. Abrasive Garnet (MESH 80) was applied as the abrasive material. Variable technological parameters: mass flow (150 / 200 / 250 / 300) and feed rate (depending on the required cut quality Q1 to Q5 determined according to the standard, calculated by the control system of the machine). Labeling of samples based on the changing technological conditions of the cutting process AWJ states Table 1.

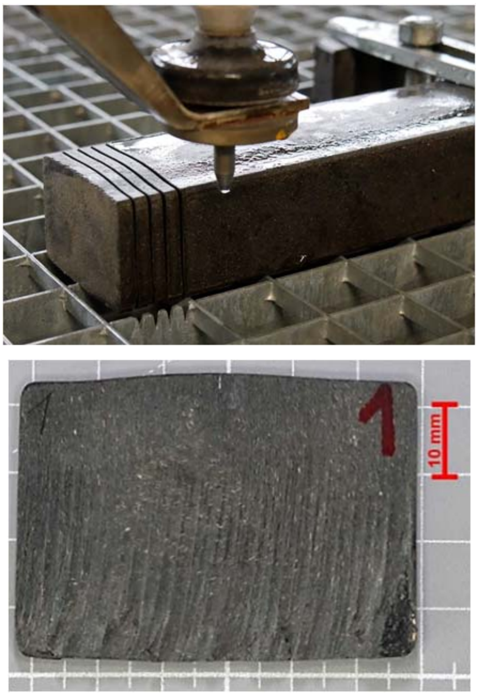

Figure 5. AWJ cutting of natural composite material (author´s archive)

The samples were evaluated by a digital microscope Dino-Lite Premier. Figure 6, 7 shows parameter of the cut determined according to Swiss standard SN 214001: 2010: Contact-free – Water jet cutting –Geometrical product specification and quality (this standard is applicable for materials which are suitable for water jet cutting – expect for tempered glass. It contains geometric product specifications, and dimensional and quality tolerances) [24]. The standard applies to materials up to a thickness of 300 mm which were measured on samples. Selected evaluated parameter: r_k – edge radius. After AWJ cutting was weight loss examined, too.

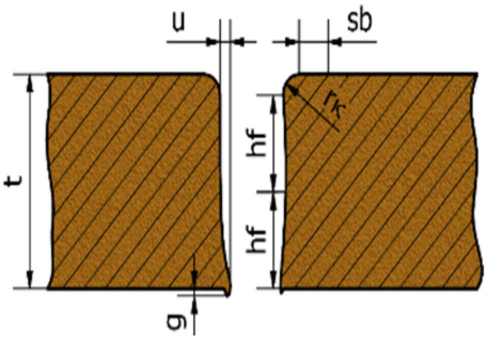

Figure 6. Location of measured parameter r_k on the sample [1]

Figure 7. Sample 17 – principle of measured parameter r_k on the sample

3. Results and Discussion

Selected evaluated parameters:

- weight loss m / Δm [g],
- edge radius r_k [mm].

After the cutting experiment, the samples were weighed using a laboratory bench scale Mettler Toledo PL303-IC (accuracy ± 0.001 g, maximal weight of sample 310 g). In relation to the nature of the composite material (connection of hydrophilic wood and hydrophobic polymer), the weighing was repeated after 48 hours. The result is → mass loss, resp. increment Δm in grams – see. Table 2.

Table 2. Mass increment /loss of single samples after AWJ cutting

	Sample č.	m [g]	m_{48} [g]	Δm [g] (%)
Set A	1	18,688	18,6	-0,088 (-0,47 %)
	2	14,207	14,071	-0,136 (-0,96 %)
	3	13,127	13,001	-0,126 (-0,96 %)
	4	15,288	15,177	-0,111 (-0,73 %)
Set B	5	15,036	14,934	-0,102 (-0,67 %)
	6	15,756	15,654	-0,102 (-0,65 %)
	7	17,9	17,809	-0,091 (-0,51 %)
	8	17,34	17,26	-0,08 (-0,46 %)
Set C	9	15,003	14,918	-0,085 (-0,57 %)
	10	16,487	16,403	-0,084 (-0,51 %)
	11	15,386	15,277	-0,109 (-0,71 %)
	12	15,067	14,963	-0,104 (-0,69 %)
Set D	13	16,939	16,873	-0,066 (-0,39 %)
	14	16,124	16,058	-0,066 (-0,41 %)
	15	14,985	14,934	-0,051 (-0,34 %)
	16	15,401	15,38	-0,021 (-0,14 %)
Set E	17	15,875	15,883	0,008 (+0,05 %)
	18	15,514	15,533	0,019 (+0,12 %)
	19	16,166	16,186	0,02 (+0,12 %)
	20	15,885	15,908	0,023 (+0,14 %)

Note: mass after AWJ cutting m [g], mass after 48 hours m_{48} [g], weight loss / gain Δm [g]

In the case of the first four sets of samples A / B / C / D (samples marked 1-16 based on the change in the technological parameters of the AWJ cutting process) a slight weight loss is visible after 48 hours. After sufficient drying of the samples, the wooden particles of the material were not soaked with liquid. In the case of set E, the values of Δm are incremental (increment is minimal), this is a set with low feed speeds v_p. Compared to the previous sets (A / B / C / D), the contact time between the water stream and the divided material was the longest (soaking of the wooden particles with the liquid and the subsequent increase in the weight of the controlled samples. The indicated increase represents tenths / hundredths of the original weight of the samples after cutting).

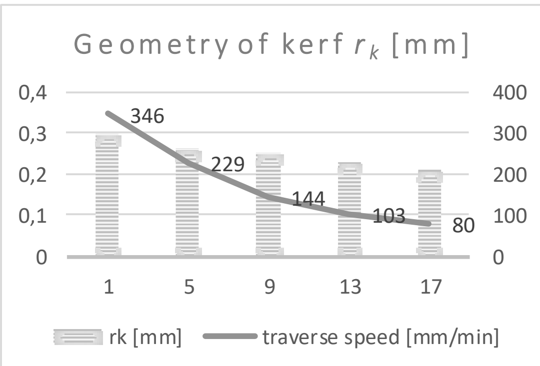

Figure 8. The changing radius of rounding r_k in relation to the decreasing value of traverse speed, for samples divided by the mass flow of the abrasive m_a = 150 kg. min^{-1}

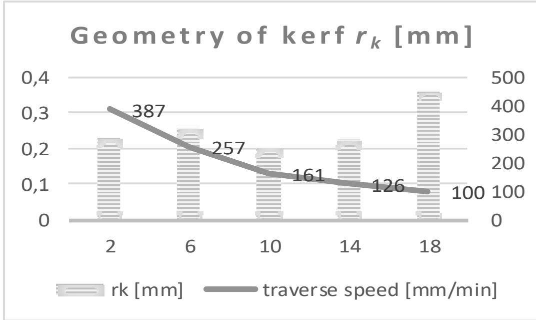

Figure 9. The changing radius of rounding r_k in relation to the decreasing value of traverse speed, for samples divided by the mass flow of the abrasive m_a = 200 kg.min^{-1}

The maximum value of the rounding radius r_k achieved is 0,358 mm for sample no. 18 (with abrasive mass flow ma = 200 kg.min^{-1}, traverse speed v_p = 100 mm.min^{-1}), the minimum achieved value of the radius r_k was recorded for sample no. 10 – is 0.2 mm (at abrasive mass flow m_a = 200 kg.min^{-1}, traverse speed v_p = 161 mm.min^{-1}). In the case of samples (Figure 8) machined with an abrasive mass flow rate of 150 kg.min^{-1} (samples: 1, 5, 9, 13, 17), the values of the primitive r_k decrease in the range of 0,298-0,211 mm (with decreasing head feed speed). In the case of the remaining three mass flows of the abrasive (200 / 250 / 300 kg.min^{-1}), this dependence of the decrease in r_k with increasing speed of the head is not recorded. The values of r_k rise / or decrease, it is not possible to clearly define their course (from Figure 9 to Figure 11).

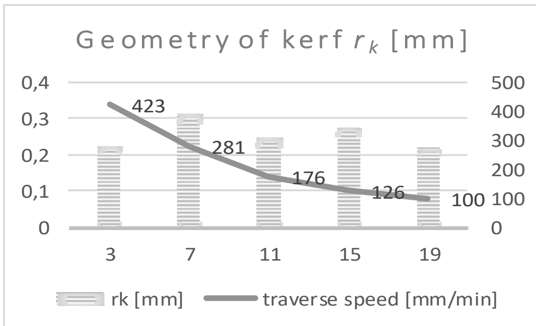

Figure 10. The changing radius of rounding r_k in relation to the decreasing value of traverse speed, for samples divided by the mass flow of the abrasive m_a = 250 kg.min^{-1}

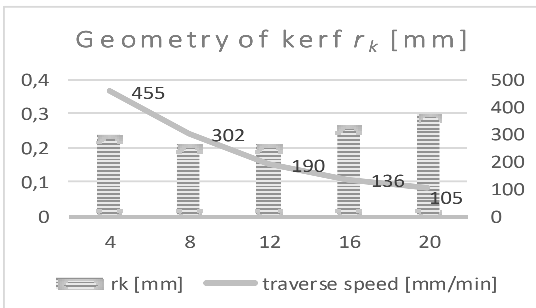

Figure 11. The changing radius of rounding r_k in relation to the decreasing value of traverse speed, for samples divided by the mass flow of the abrasive m_a = 300 kg.min^{-1}

Standard SN 214001: 2010 describes the level of quality based on the characteristics listed above. One of them is the investigated parameter r_k. However, the standard does not define it for the respective quality levels Q1-Q5.

4. Conclusion

The AWJ cutting technology represents one of the possibilities of division of WPC materials (its application excludes the phenomenon of melting the plastic matrix of the composite material). In relation to the nature of the technology and its basis, it is necessary to pay attention to a longer drying time for absorbent materials. At lower head feed speeds applied, weight gains are positive. However, it is not possible to precisely define the dependence of the contact time of the water stream and the increase in the weight of the split samples, in relation to the inhomogeneity of the material (the percentage of wood mass may differ slightly in individual split samples). The investigated parameter r_k is defined by the relevant standard (SN 214001:2010), but no specific values are set. In relation to this fact, the orientation is also current in this direction.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-20-0514 (Research of the influence of technological parameters of abrasive water jet machining on the surface integrity of tool steels) and project KEGA no. 032TUKE-4/2021: Transfer and implementation of knowledge in the field of energy beam technologies into study programs of technical secondary schools supporting dual education.

References

[1]. Klyosov, A. A. (2007). *Wood-plastic composites*. John Wiley & Sons.

[2]. Niska, K. O. & Mohini, S. (2008). *Wood-polymer composites.* CRC Press.

[3]. Faruk, O., & Bledzki, A. K. (2011). Wood plastic composite: present and future. *Wiley Encyclopedia of Composites*, 1-20.

[4]. Zeng, W., et al. (2012). Laser insentity effect on mechanical properties of wood-plastic composite parts fabriced by selective laser sintering. *Journal of Thermoplastic Composite Materials*, *26*(1), 125-136.

[5]. Chaharmahali, M., et al. (2008). Mechanical and Physical Properties of Wood-Plastic Composite Panels. *Journal of Reinforced Plastics and Composites*, *29*(2), 310-319.

[6]. Khan, M. A., & Ali, K. I. (1992). Studies of physico–mechanical properties of wood and wood plastic composite (WPC). *Journal of applied polymer science*, *45*(1), 167-172.

[7]. Bhaskar, K., Jayabalakrishnan, D., Kumar, M. V., Sendilvelan, S., & Prabhahar, M. (2021). Analysis on mechanical properties of wood plastic composite. *Materials Today: Proceedings*, *45*, 5886-5891.

[8]. Delviawan, A., et al. (2019). The effect of wood particle size distribution on the mechanical properties of wood-plastic composite. *Journal of Wood Science*, *45*(7), 5886-5891.

[9]. Ayrilmis, N., Kaymakci, A., & Güleç, T. (2015). Potential use of decayed wood in production of wood plastic composite. *Industrial Crops and Products*, *74*, 279-284.

[10]. Khonsari, A., Taghiyari, H. R., Karimi, A., & Tajvidi, M. (2015). Study on the effects of wood flour geometry on physical and mechanical properties of wood-plastic composites. *Maderas. Ciencia y tecnología*, *17*(3), 545-558.

[11]. Friedrich, D. (2022). Success factors of Wood-Plastic Composites (WPC) as sustainable packaging material: A cross-sector expert study. *Sustainable Production and Consumption*, *30*, 506-517.

[12]. Ashori, A. (2008). Wood–plastic composites as promising green-composites for automotive industries!. *Bioresource technology*, *99*(11), 4661-4667.

[13]. Najafi, S. K. (2013). Use of recycled plastics in wood plastic composites–A review. *Waste management*, *33*(9), 1898-1905.

[14]. Wax granulate pellets (2022). Fiona Ariva. Retrieved from: https://fionaariva.com/products/clay-beige-100pcs-sealing-wax-granules-pellets-beads [accessed: 20 August 2022].

[15]. Wood shavings (2022). Freepik. Retrieved from: https://www.freepik.com/premium-photo/curly-wood-shaving-isolated-white-close-up_13049002.htm [accessed: 20 August 2022].

[16]. Pigments (2022). Accent. Retrieved from: https://www.accentpmu.com/pigments/ [accessed: 20 August 2022].

[17]. Wood Plastic Composites (2022). Plast Europe. Retrieved from: https://www.plasteurope.com/news/WOOD_PLASTIC_COMPOSITES_t234216/ [accessed: 22 August 2022]

[18]. Vinayagamoorthy, R., & Rajmohan, T. (2018). Machining and its challenges on bio-fibre reinforced plastics: A critical review. *Journal of Reinforced Plastics and Composites*, *37*(16), 1037-1050.

[19]. Górski, J., Podziewski, P., & Borysiuk, P. (2022). The Machinability of Flat-Pressed, Single-Layer Wood-Plastic Particleboards while Drilling—Experimental Study of the Impact of the Type of Plastic Used. *Forests*, *13*(4), 584.

[20]. Hloch, S., & Valíček, J. (2012). Topographical anomaly on surfaces created by abrasive waterjet. *The International Journal of Advanced Manufacturing Technology*, *59*(5), 593-604.

[21]. Valíček, J., Harničárová, M., Panda, A., Hlavatý, I., Kušnerová, M., Tozan, H., ... & Vaclavik, V. (2016). Mechanism of creating the topography of an abrasive water jet cut surface. In *Machining, joining and modifications of advanced materials 61*, 11-120. Springer, Singapore.

[22]. Lehocka, D., et al. (2017). *Study of surface topography of CW004A copper after PWJ disintegration.* 2nd EAI International Conference on Management of Manufacturing Systems.

[23]. Hutyrová, Z., Zajac, J., Michalik, P., Mitaľ, D., Duplák, J., & Gajdoš, S. (2015). Study of surface roughness of machined polymer composite material. *International Journal of Polymer Science*, 406-411.

[24]. SN 214001:2010. (2013). Geometrical-free cutting - water jet cutting - geometrical specification and quality. Swiss Standards-Vereiningung: Zurich, Switzerland.