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INFLUENCE OF TECHNOLOGICAL PARAMETERS ON LAGGING SIZE IN CUTTING PROCESS OF SOLID WOOD BY ABRASIVE WATER JET

Štefan Barcík, Monika Kvietková, Miroslav Gašparík
Czech University of Life Sciences, Faculty of Forestry and Wood Sciences
Department of Elementary Wood Processing
Prague, Czech Republic

Richard Kminiak
Technical University, Faculty of Wood Sciences and Technology
Department of Woodworking
Zvolen, Slovak Republic

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ABSTRACT

The publication deals with the influence of selected technological parameters (a feed speed and an abrasive mass flow rate) on dimension of water jet lagging during native wood cutting (Pedunculate Oak, European Beech, Norway Spruce) in the cutting process realized by abrasive water jet. The experiment proceeded within a range of usable values of the feed speed (0.2 – 0.6 m.min^{-1}) and of the abrasive mass flow rate (250 – 450 g.min^{-1}) and within basic models of the native wood cutting (that come from tangential and radial type of sawn wood and from two cutting directions along the grain and across the grain). The results refer to power potential of the abrasive water jet and its influence on the qualitative factors.

KEYWORDS: Abrasive water jet (AWJ), abrasive water jet lagging, feed speed, abrasive mass flow rate.

INTRODUCTION

In a case of the abrasive water jet it deals with a machining process accomplished by liquid jet enriched by abrasive solid thus it deals with the erosive process of a high speed (Engman 1993, Matuška 2003, Barcík 2007). The most often used abrasive solids are natural garnet, alumina, mineral sand, silica sand and steel wire blasting medium.

Like all jet technologies of the high energy also AWJ jet left visible milling on the machined surfaces. The given milling influences negatively quality of the machined surfaces as well as products' accuracy to shape (Lisičan 1996, Maňková 2002, Beer 2007, Barcík et al. 2011b). The milling starts in a certain depth under the surface a gradually deepens. The machined area consists of a smooth zone and of a rough - milled zone (Fig. 1) then. A path of the water jet through material and the water jet lagging itself are visible on the milling (Gerencsér and Bejo 2003, Barcík et al. 2011a, Kminiak and Barcík 2011a).

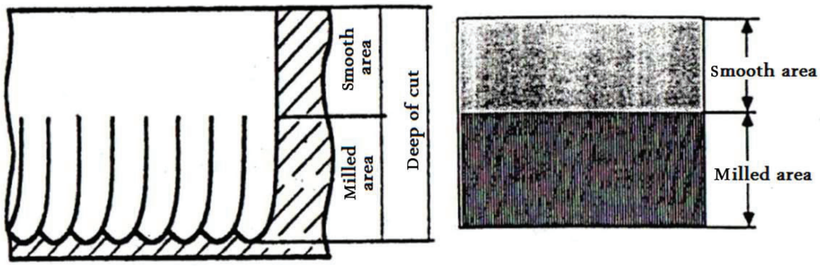

Fig. 1: Two zones created after cutting by AWJ jet (Maňková 2002).

Hashish (1991) in his theory of the AWJ cutting, provides the following justification of the given phenomenon. The jet breaks down the material and gradually loses its kinetic energy and diffracts. By that it creates two typical zones that change the texture of surface.

A relatively smooth area in the upper part of the cut is a result of the cutting attrition and the second milled area in the lower part of the cut is created as a consequence of deformation wearing during cutting by AWJ jet (Engman 1993, Krajný 1998, Kminiak and Barcík 2011b).

The amount of delivered energy is dependent on the technological parameters of cutting process. It depends especially on the water jet pressure, the abrasive mass flow rate and the feed speed (Reisner 2004, Barcík et al. 2009, Barcík and Kvietková 2011). As regards the water jet pressure; it is kept on maximal levels that are available on the given device. The last two parameters are changed according to requirements on the quality of produced surface.

Influence of feed speed

By decreasing of the feed speed, the maximal depth of the cut markedly increases or the cutting face quality improves. At slower speeds more abrasive particles strike upon material surface and the power needed for material erosion increases (Kminiak and Barcík 2011a). Hashish (1991) and Krajný (1998) have defined this amount of the particles according to Eq. 1:

$$PDD = \frac{m_a}{v_f} \tag{1}$$

where: *PDD* - abrasive particles density division (the amount of particles necessary for a groove generation with a nominal length upon given parameters) (kg.m^{-1}),
m_a - abrasive mass flow rate (kg.s^{-1}),
v_f - feed speed of water jet movement against material (m.s^{-1}), and also the energy density of particles according to Eq. 2:

$$EDD = \frac{1}{2} * PDD * v_a^2 \tag{2}$$

where: *EDD* - distribution of energy density of abrasive particles (the amount of energy reverted to a unit of the generated groove length) (J.m^{-1}),

v_a - speed of abrasive coming from the head ($m.s^{-1}$).

Influence of abrasive mass flow rate

The influence of abrasive mass flow rate on the cutting process executed by the abrasive water jet is the following: during increasing of the delivered amount of abrasive material to a flow of the clean liquid, the attained depth of the cut increases (Havlík 1995, Krajný 1998, Gerencsér and Bejó 2003). The kinetic energy of the abrasive particles (E_a) increases. This energy can be calculated according to Eq. 3:

$$E_a = \frac{1}{2} * m_a * v_a^2 \tag{3}$$

where: E_a - kinetic energy of the abrasive particles ($J.s^{-1}$),
m_a - abrasive mass flow rate ($kg.s^{-1}$),
v_a - speed of abrasive coming from the head ($m.s^{-1}$).

Also increasing of the abrasive mass flow rate has a positive influence on the quality of machined surface.

Increasing of the abrasive mass flow rate is limited by so called critical mass flow rate under which the cut depth does not increase any more but on the contrary it decreases. It is caused by the fact that the lesser amount of abrasive particles "is distributed" more evenly within jet's internal diameter area whereas if the particles amount is above the critical value, a part of particles' kinetic energy is consumed on their reciprocal interference, on their collisions (Krajný 1998, Barcík 2009).

There is a reason why it is necessary to know a length of the water jet lagging. It must be considered when you want to change a direction of cutting. By that you avoid eventual not finishing of the material cut at a work piece corners as well as in a case of allowances on the machining.

MATERIAL AND METHODS

Our chosen methods of experimental test were first introduced by Kminiak (2010). Based on these previous tests our research had following materials, parameters and methods of determination:

Test samples

- Species composition of the test samples: Pedunculate oak (*Quercus robur*), European beech (*Fagus sylvatica*), Norway spruce (*Picea abies*),
- Dimensions of the test samples: thickness (25/50/75 mm), width (180 mm), length (500 mm),
- Type of sawn-wood of the test samples: quarter-sawn wood/flat-sawn wood
- Moisture content of the test samples: 8 %.

Parameters of cutting process

Cutting of the test samples was carried out in the premises of the firm DEMA Ltd. Zvolen, Slovakia. The test sample was cut according to a cutting scheme (Fig. 2). Corresponding combinations of feed speed are summarized in the Tab. 1. For every combination of tree species, thickness, and kind of sawn-wood there were always carried out cuttings on three samples in order to eliminate the influence of specific properties of the given sample. At cutting of each sample the following parameters were observed:

- Cutting liquid pressure: 400 MPa,
- Abrasive: Australian Garnet GMA (grain composition 80 MESH),
- Abrasive jet diameter: 1 mm,
- Water jet diameter: 0.013 inch = 0.33 mm,
- Nozzle distance above a work piece: 4 mm.

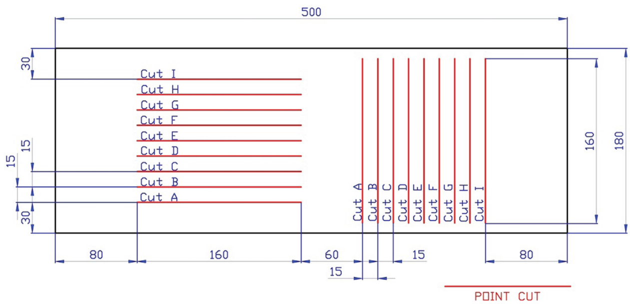

Fig. 2: Cutting plan of tested samples.

Tab. 1: Combination of feed speed and abrasive mass flow attributable to each place of cut.

Cut	A	B	C	D	E	F	G	H	I
Feed speed v_f (m.min^{-1})	0.6	0.6	0.6	0.4	0.4	0.4	0.2	0.2	0.2
Abrasive mass flow m_a (g.min^{-1})	250	350	450	250	350	450	250	350	450

Evaluation of water jet lagging

Definition of terms: L - water jet lagging (Fig. 3) is the lagging of the jet path while breaking down the material, a difference of X coordinate of water jet path at the input and at the output of the water jet to and from material (Hashish 1991, Kminiak and Barcík 2011a).

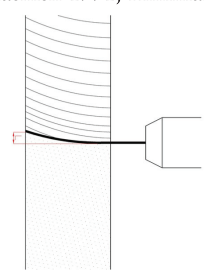

Fig. 3: Abrasive water jet lagging.

Working procedure

1. Creation of a digital photo of the surface together with a reference gauge:

Creation of measure points on samples. On each side were carried out ten measurements according to a scheme (Fig. 4)

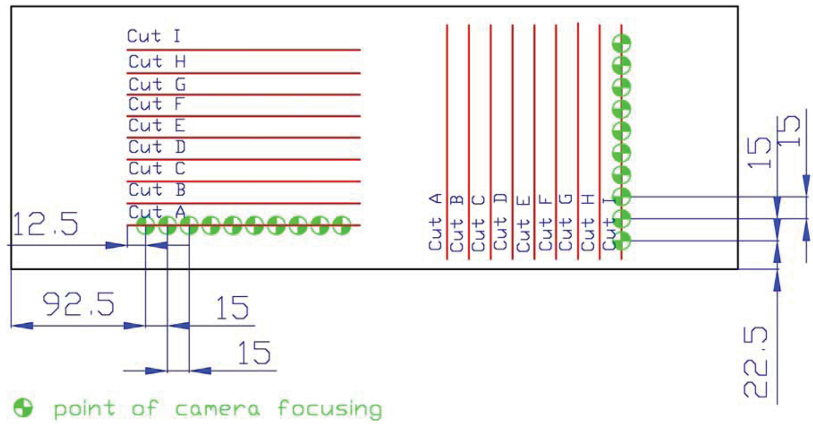

Fig. 4: Places of measurements on machined surface.

2. Cutting path parameters measurement – lagging

3. Transfer of proportional dimensions to real dimensions

$$L = \frac{L_p * a}{a_p} \quad (4)$$

where: L - the real lagging of water jet (mm),
L_p - the proportional dimension of water jet lagging (--),
a - the real dimension of reference gauge unit (mm),
a_p - the proportional dimension of reference gauge unit (--).

4. Statistical evaluation of data

RESULTS AND DISCUSSION

On base of statistic evaluation it is possible to claim that both monitored technological parameters are important as regards a statistic point of view. At the same time the feed speed was proved as a more important statistic parameter.

Within the cutting process, on the one hand, there is the abrasive water jet which is a carrier of the power needed for material splitting (the amount of this energy delivered per a unit of the cut path is dependent on the feed speed and on the mass flow rate of the abrasive). And on the other hand there is material, a carrier of the resistance against cutting that starves the AWJ power (the resistance value is dependent on material features and on a particular model of cutting). A compliant indicator of these two variables interaction is precisely the AWJ lagging because increase of the amount of energy or decrease of the material resistance becomes evident as the AWJ lagging and viceversa.

Influence of feed speed

The presented results (Fig. 5 and Tab. 2) confirm the following logic hypothesis: If the feed speed rises the amount of energy delivered per a unit of the cut path drops what gives rise to the AWJ lagging enhancement. In quantification, the increase of the feed speed from 0.2 to 0.4 m.min^{-1} means enhancement of the AWJ lagging by 0.88 mm* while the increase from 0.4 to 0.6 m.min^{-1} means enhancement of the AWJ lagging by 1.04 mm*. (*the given figure is related to Tab. 1).

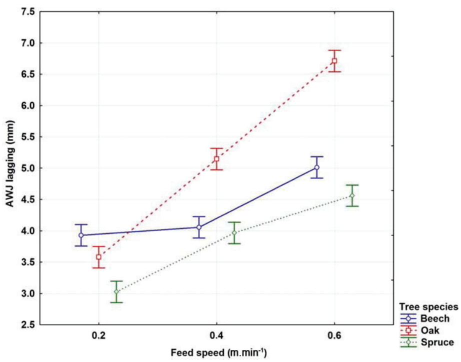

Fig. 5: Influence of feed speed on AWJ lagging.

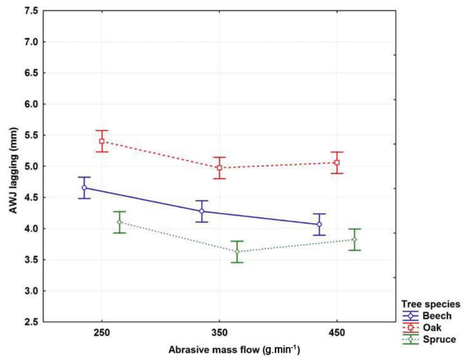

Fig. 6: Influence of abrasive mass flow rate on AWJ lagging.

Tab. 2: Average values of AWJ lagging for various feed speeds.

Tree species	Feed speed (m.min^{-1})	AWJ lagging Mean (mm)	Std. err. (mm)	-95.00 % (mm)	+95.00 % (mm)	N
European beech	0.2	3.927830	0.087071	3.756900	4.098760	96
	0.4	4.056586	0.087071	3.885656	4.227516	96
	0.6	5.011522	0.087071	4.840592	5.182452	96
Pedunculate oak	0.2	3.579821	0.087071	3.408891	3.750750	96
	0.4	5.143831	0.087071	4.972901	5.314760	96
	0.6	6.710304	0.087071	6.539374	6.881234	96
Norway spruce	0.2	3.025035	0.087071	2.854106	3.195965	96
	0.4	3.965097	0.087071	3.794168	4.136027	96
	0.6	4.559913	0.087071	4.388983	4.730842	96

Our conclusion is that by decrease of the feed speed, there is longer operation of the abrasive water jet per a unit of the cutting gap. More abrasive particles go through the given place then. These abrasive particles are the carrier of the bigger amount of energy. They are able to remove more material from a place of the cut independently on its height or width.

The amount of energy per a unit of the cut path length can be expressed by means of EDD parameter – distribution of energy density of abrasive particles that can be quantified according to the Eq. 2. Appropriate values of the EDD parameter for particular combinations of the feed speed and abrasive mass flow rate are stated in Tab. 3. The rise of the feed speed from 0.2 to 0.4 m.min^{-1} decreases energy density of abrasive particles by 1/2* and the rise from 0.4 m.min^{-1} to 0.6 m.min^{-1} decreases energy density of abrasive particles by 1/3*. (*the given figure is related to Tab. 2)

The most important demonstration of the delivered power decrease in relation with the feed speed increase is the water jet lagging in the cut. However, it also becomes evident in the other indicators of the cut quality. Decrease of the feed speed, as stated in publications of Barcík et al. (2011b), Kminiak and Barcík (2011a) or Barcík et al. (2009), causes reduction of the cut gap width on the side of the AWJ input to material and on the contrary its extension on the side of the AWJ output. Barcík et al. (2011a, b), and Barcík and Kvietková (2011) also observed that decrease of the feed speed causes enlargement of the angle of cut sides' declination and lightly worsens a degree of surface roughness.

Tab. 3: Distribution of energy density of abrasive particles for various feed speeds and abrasive mass flows.

Abrasive mass flow ($g.min^{-1}$)	**Feed speed ($m.min^{-1}$)**		
	0.2	**0.4**	**0.6**
	EDD - distribution of energy density of abrasive particles ($J.m^{-1}$)		
250	489515	244757	163171
350	685321	342660	228440
450	881127	440563	293709

Influence of abrasive mass flow rate

Influence of the abrasive mass flow rate on the AWJ lagging is presented by Fig. 6 and Tab. 4. The stated increase of the abrasive mass flow rate from 250 to 350 $g.min^{-1}$ causes the decrease of the AWJ lagging by 0.43 mm*. The change from 350 to 450 $g.min^{-1}$ does not take effect as regards the statistic importance. It causes only moderate increase of the average value of the AWJ lagging by 0.02 mm*. (*the given figure is related to Tab. 3)

Tab. 3: Average values of AWJ lagging for various abrasive mass flows.

Tree species	**Abrasive mass flow ($g.min^{-1}$)**	**AWJ lagging**				**N**
		Mean (mm)	**Std. err. (mm)**	**-95.00 % (mm)**	**+95.00 % (mm)**	
European beech	250	4.654694	0.087071	4.483764	4.825623	96
	350	4.276483	0.087071	4.105553	4.447412	96
	450	4.064762	0.087071	3.893832	4.235692	96
Pedunculate oak	250	5.402658	0.087071	5.231728	5.573588	96
	350	4.973585	0.087071	4.802655	5.144515	96
	450	5.057712	0.087071	4.886782	5.228642	96
Norway spruce	250	4.100753	0.087071	3.929823	4.271683	96
	350	3.626863	0.087071	3.455933	3.797793	96
	450	3.822430	0.087071	3.651500	3.993360	96

Explanation of the AWJ lagging decrease under the change of abrasive mass flow rate from 250 to 350 $g.min^{-1}$ lies in increase of the abrasive particles amount per a unit of the cut path. These particles dispose of higher cutting energy. The same change did not become evident in a case of further increase of the abrasive mass flow rate from 350 to 450 $g.min^{-1}$ because the volume of 350 $g.min^{-1}$ particles appeared the optimal one. Further increase of the particles would be almost counter-productive because the AWJ lagging would increase as a consequence of the energy drop caused by mutual collisions of the particles.

The same as in the case of the feed speed also in the case of abrasive mass flow rate, the qualitative parameters of the cut have been influenced. Generally, we came to the conclusion that the influence of the abrasive mass flow rate decrease is identical with the influence of the feed speed increase.

However, our results are difficult to compare with other authors, since no one deal with such a broad complex experiments in the subject under consideration.

CONCLUSIONS

The abrasive water jet lagging is the most important indicator of the amount of energy delivered to the cut and of the power economy. Within the monitored technological parameters we can claim that the increase of the feed speed causes the increase of the AWJ lagging in the cut. The decrease of the abrasive mass flow rate also causes the increase of the AWJ lagging. By a change of the monitored technological parameters the increase of the lagging is not bigger than 1 mm. The AWJ lagging increase is the indicator of worsening of the qualitative parameters of the cut as regards the cutting gap width, cut sides' declination and surface roughness. From the presented results it becomes evident that under optimizing of the monitored parameters it is not necessary to consider the allowance on machining because the AWJ cutting is comparable with a technology of face milling.

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Štefan Barcík, Monika Kvietková, Miroslav Gašparík *
Czech University of Life Sciences
Faculty of Forestry and Wood Sciences
Department of Elementary Wood Processing
Kamýcká 1176
Cz-165 21 Prague 6 - Suchdol
Czech Republic
Phone: +421 949 170014
Corresponding author: gathiss@gmail.com

Richard Kminiak
Technical University
Faculty of Wood Sciences and Technology
Department of Woodworking
T. G. Masaryka 24
Sk-960 53 Zvolen
Slovak Republic