

# Possibilities of homogenization of the kerf width created by the technology of abrasive water-jet cutting

R. KMINIAK<sup>1</sup>, Š. BARCÍK<sup>2</sup>

<sup>1</sup>*Department of Wood Working, Faculty of Wood Sciences and Technology, Technical University in Zvolen, Zvolen, Slovak Republic*

<sup>2</sup>*Department of Wood Processing, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, Prague, Czech Republic*

**ABSTRACT:** The paper deals with the possibilities of homogenization of the kerf width by proper choice of the respective feed rate and abrasive mass flow for particular models of cutting. The introductory part is devoted to reasons for the kerf width variability in dependence on the models of cutting, as well as to the methods of determining the kerf width in cutting of solid wood by abrasive water jet. In the conclusion are presented the results concerning the development of kerf width in the range of commonly used feed rates and abrasive mass flows.

**Keywords:** kerf width; influence of feed rate; influence of abrasive mass flow

The potential of the technology of cutting by abrasive water jet (AWJ) is hidden in a possibility of creation of a complicated shape of cuts and in a small kerf width. The above-mentioned advantages simply predetermine the given technology to applications such as manufacture of intarsia and inlaid parquet floors.

A certain complication of its use is caused by the dependence of the kerf width on a particular model of cutting due to wood anisotropy. A change in the model of cutting can influence the kerf width in the range of  $\pm 15\%$ . This phenomenon can be influenced by an optimal choice of feed rate and abrasive mass flow as the main independent technical and technological parameters in dependence on the given model of cutting.

## Theoretical analysis of the problem

The technology of cutting by abrasive water jet uses as a tool the liquid water jet enriched with the particles of abrasive material (REISNER 2004).

The mechanism of a reduction of working material by water-jet cutting is similar to the mecha-

nism of material reduction by sanding. From this aspect, the abrasive water jet belongs among polygonal tools with an indefinable cutting edge (ENGEMANN 1993; MAŇKOVÁ 2000; BEER 2007). Cutting wedges are represented by grains of the abrasive. The orientation of abrasive grains is quite random, and their greatest concentration is in a coating zone – on the surface of the abrasive water jet. The concentration of the abrasive toward the core of the water jet steeply decreases. The resulting worked surface consists of cutting facets left by cutting wedges (grains of abrasive) (HASHISH 1991; KRAJNÝ 1998; GERENCSEI, BEJÓM 2003). The energy supplied by abrasive water jet to the point of cutting depends on the pressure of the liquid, mass flow of abrasives, and feed rate (MATUŠKA 2003; BARCÍK 2007).

The kerf width subsequently depends on the amount of supplied energy by water jet to the point of cutting and on the resistance of material against cutting (HAVLÍK 1995; KULEKCI 2002).

The resistance of material depends on the particular anatomical structure at the point of cutting (orientation of cell elements, their size, and magnitude of adhesive properties among cell elements).

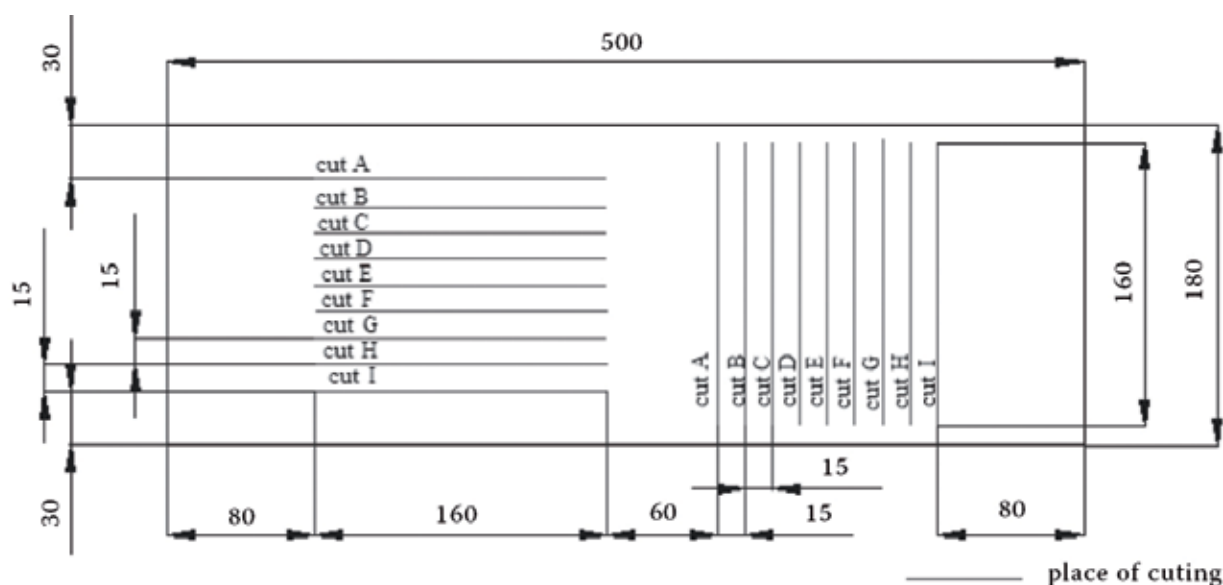


Fig. 1. Cutting plan of the test samples

To propose the basic models of cutting the type of sawn timber (quarter sawn and flat sawn) and the direction of cutting (along and across the grain) are taken into account (LISIČAN 1996).

In general, we can state that the kerf width in quarter-sawn timber on the input side of AWJ into material will be larger on average by 4.6% and on the output side of AWJ from material it will be larger by 8.3% than in flat-sawn timber.

A change in the direction of cutting will demonstrate itself more markedly. The change from longitudinal to cross-sectional cutting will cause the widening of the kerf width by 21% on the input side of AWJ into material and the narrowing of the kerf width by 22% on the output side of AWJ from material (KMINIAK 2010; KMINIAK et al. 2011).

Let us consider a model situation in the cutting of quarter-sawn 25 mm thick beech sawn timber for the greatest effectiveness of the process under maximal cutting conditions (which means for the given case the feed rate of  $0.6 \text{ m} \cdot \text{min}^{-1}$  and abrasive mass flow of  $450 \text{ g} \cdot \text{min}^{-1}$ ). In cutting along the grains the kerf width on the input side of AWJ is 1.13 mm and in cutting across the grains it is 1.27 mm. In the case of flat-sawn timber, compared to quarter-sawn wood, the kerf width on the input side of AWJ is 0.91 mm, and across the grains 1.03 mm (KMINIAK 2010; KMINIAK, BARCIK 2011).

There is raised a condition of possibility of the kerf width homogenization in the context of the above-mentioned factors (type of sawn timber and direction of cutting) belonging among the material parameters which cannot be influenced. One way how to eliminate differences in the kerf width is an

optimization of technical and technological parameters, namely of feed rate ( $v_f$ ) and of abrasive mass flow ( $m_a$ ). So this paper is devoted particularly to such optimization.

## MATERIAL AND METHODS

The chosen methods of experimental studies by KMINIAK (2010).

### Parameters of test samples

- Tree species of the test samples: pedunculate oak (*Quercus robur*), European beech (*Fagus sylvatica*), Norway spruce (*Picea abies*),
- thickness of the test samples: 25 mm/50 mm/75 mm,
- required width of the test samples:  $w = 180 \text{ mm}$  ( $\pm 2.5 \text{ mm}$ ),
- required length of the test samples:  $l = 500 \text{ mm}$  ( $\pm 5 \text{ mm}$ ),
- type of sawn-timber of the test samples: quarter-sawn timber/flat-sawn timber,
- moisture content of the test samples:  $w = 8\%$  ( $\pm 2\%$ ).

### Cutting process

Cutting of the test samples was carried out according to cutting operations (Fig. 1) on the premises of the DEMA Ltd. Company in Zvolen

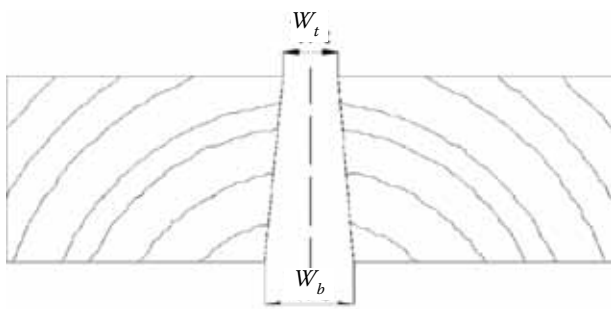


Fig. 2. Illustration of the measured characteristics of kerf width

(Slovakia). The equipment was assembled on the basis of components of the FLOW International Corporation (U.S.) by the PTV, Ltd. (Praha, Czech Republic). It consists of a PTV 37-60 Compact high-pressure pump and a work table with WJ 20 30 D-1Z water-jet head supplied by the PTV Company.

### Definition of measured values

The definition of measured values is presented in Fig. 2, where:

- $w_t$  – *kerf width on the side of water jet input into material (top kerf width)*: it is the kerf width created by passing the abrasive water jet through material measured on the side of water jet penetration into material,
- $w_b$  – *kerf width on the side of water jet output from material (bottom kerf width)*: it is the kerf width created by passing the abrasive water jet through material measured on the side of penetration of water-jet output from material.

### Operating procedure

- *Creation of digital photography of the kerf width together with a reference scale* (the kerf width was measured on the input and output side of the cut – Fig. 2) where ten measurements were

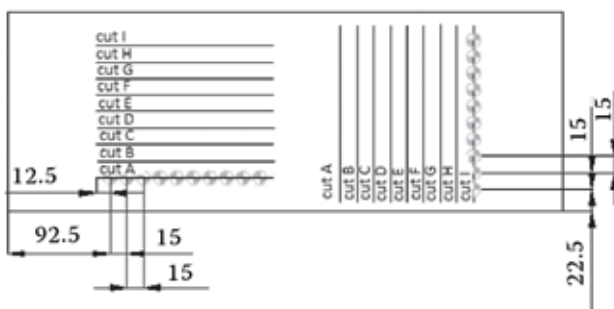


Fig. 3. Points of measuring of the kerf width

carried out on each side, and the distance among them was 15 mm (Fig. 3),

- *measuring of the kerf width*,
- *conversion of relative dimensions to real ones and non-binding statistic evaluation of data.*

Note: Measuring of the bottom kerf width on the side of water jet output from material was hindered by the rippled cutting edge contour (Fig. 4b) as for practical use the maximal size of the kerf is important (from the viewpoint of determining allowances for possible further working). The kerf width (Fig. 4a) was measured as a distance of the two most remote parallel tangents to the cutting edge (Fig. 5), where an evaluated cutting edge length was 15 mm.

## RESULT AND DISCUSSION

The interpreted results issue from the basic summary file containing three tree species (pedunculate oak, European beech, and Norway spruce), two types of sawn timber (quarter-sawn timber/flat-sawn timber), two directions of cutting (along the grains/across the grain), and two thicknesses of sawn timber (25/50 mm).

### Influence of feed rate ( $v_f$ )

Based on the evaluation of the effect of feed rate on the top kerf width at the input of AWJ into material (Fig. 6 and Table 1) we can state that the dependence of the top kerf width at the input of AWJ into material is inversely proportional to  $v_f$ . A reduction of feed rate by  $0.2 \text{ m} \cdot \text{min}^{-1}$  causes the widening of the kerf width by 0.06 mm on average (Table 1).

The given demonstration can be justified by the fact that a reduction of feed rate causes a longer action of abrasive water jet on the unit length of the kerf width, i.e. a greater number of abrasive particles pass through the given point. These particles are holders of a greater amount of energy, and they are able to take off more material from the cutting point along its height and also along its width.

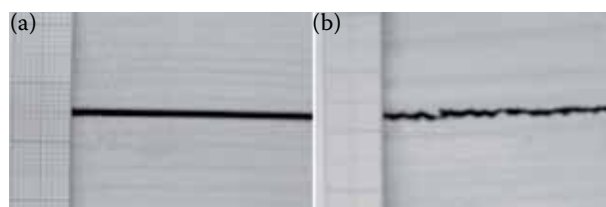


Fig. 4. Digital picture of the kerf on mock-up sample: (a) kerf width on the side of water-jet input into material (top kerf width); (b)  $w_b$  – kerf width on the side of water-jet output from material (bottom kerf width)

Table 1. Kerf width in dependence on feed rate and kind of tree species

Tree species	Feed rate (m·min <sup>-1</sup> )	Average value of kerf width	
		top kerf width (mm)	bottom kerf width (mm)
Norway spruce	0.6	1.01	1.18
	0.4	1.07	1.16
	0.2	1.15	1.19
Pedunculate oak	0.6	1.05	2.41
	0.4	1.10	1.95
	0.2	1.17	1.19
European beech	0.6	1.13	1.53
	0.4	1.14	1.39
	0.2	1.20	1.55

The amount of energy falling on the unit length of the cut line can be expressed by the *EDD* parameter – distribution of the energy density of abrasive particles (KRAJNÝ 1998). Respective values of the *EDD* parameter for particular combinations of feed rate and abrasive mass flow are shown in Table 2. By increasing the feed rate from 0.2 m·min<sup>-1</sup> to 0.4 m·min<sup>-1</sup> the energy density of abrasive particles will decrease by half (Table 2); by increasing the feed rate from 0.4 m·min<sup>-1</sup> to 0.6 m·min<sup>-1</sup> the energy density of abrasive particles will decrease by a third (Table 2).

The influence of feed rate on the kerf width on the side of AWJ output from material is documented in Fig. 7.

The effect of a change of feed rate concerning the kerf width on the output side of AWJ from material is an opposite one. The inverse proportion became a direct proportion and a reduction of feed rate causes the narrowing of the kerf width. In absolute terms – a reduction of feed rate by 0.2 m·min<sup>-2</sup> causes the reduction of kerf width by 0.2 mm (Table 1).

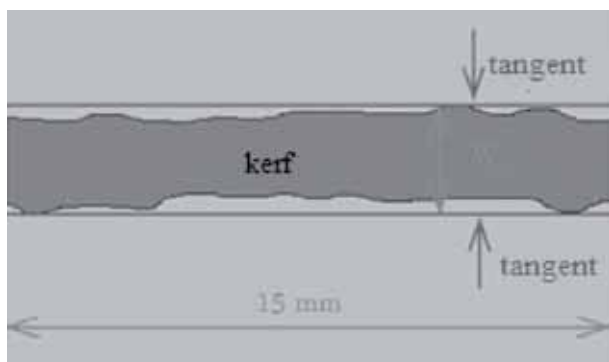


Fig. 5. Measuring of the bottom kerf width on the side of output the water-jet from material

Table 2. Distribution of the density of energy of abrasive particles for considered combinations of feed rate and mass flow of abrasive

Abrasive mass flow (g·min <sup>-1</sup> )	Feed rate (m·min <sup>-1</sup> )		
	0.2	0.4	0.6
<i>EDD</i> – distribution of energy density of abrasive particles (J·m <sup>-1</sup> )			
250	489,515	244,757	163,171
350	685,321	342,660	228,440

Analogically, a greater quantity of abrasive particles which are able to take off more material will pass through the given point (the AWJ energy potential will increase). At the same time it is necessary to take into account the course of water-jet path along the height of the cut, namely its lagging. A greater number of particles in the space will manifest themselves by a decrease of the water-jet lagging and not by a further widening of the kerf width. A reduction of feed rate by 0.2 m·min<sup>-1</sup> decreases the AWJ lagging on average by 0.96 mm. It is necessary to emphasise that despite its reduction the kerf width will still remain wider on the output side of AWJ from material than it is on its input side.

Comparing our results with the already existing knowledge we arrived at different conclusions in some cases. GERENCSEÉR and BEJO (2007) stated that the kerf width on the side of AWJ input into material was wider than on the side of AWJ output from material. We explain it on the basis of a difference in the pressure levels. While GERENCSEÉR and BEJO (2007) worked with the pressure of working medium 300 MPa, in our case it was 400 MPa, which substantially changed the magnitude of supplied energy by abrasive water jet. With regard to

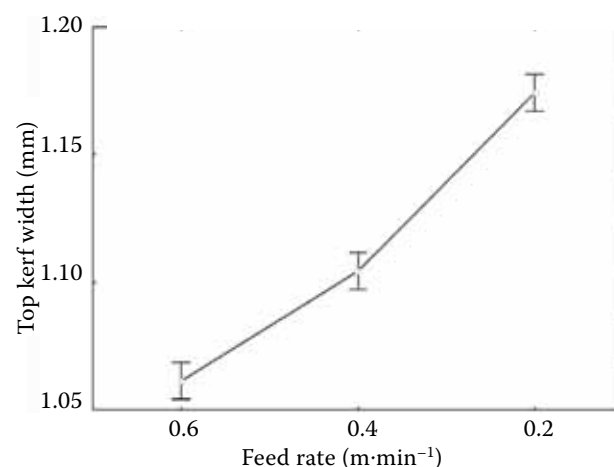


Fig. 6. Influence of the feed rate on the kerf width on the top side of AWJ input into material

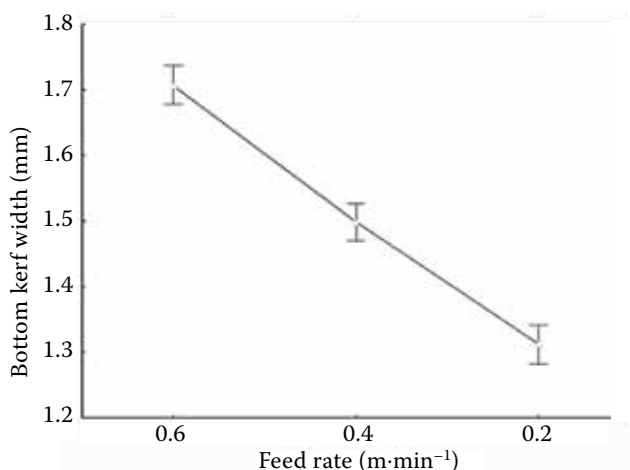


Fig. 7. Influence of the feed rate on the kerf width on the side of AWJ output from material

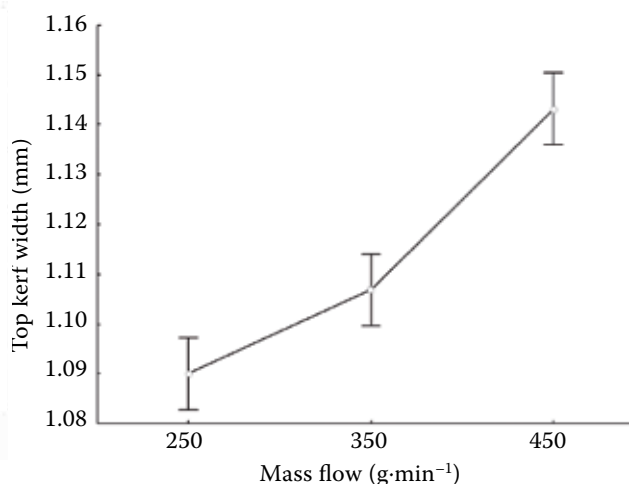


Fig. 8. Influence of the abrasive mass flow on kerf width on the input side of AWJ into material

the influence of technological parameters on the kerf width, the results of experiments are comparable with the results published so far.

### Influence of abrasive mass flow ( $m_a$ )

Abrasive mass flow together with the feed rate belong among technological parameters in which we can equally observe the different influence on the kerf width at AWJ input into material and its output from material.

The kerf width on the input side of abrasive water jet into material becomes larger with the increase of abrasive mass flow (Fig. 8). An increase of abrasive mass flow from 250 g·min<sup>-1</sup> to 350 g·min<sup>-1</sup> causes the widening of the kerf by 0.02 mm on average, and the increase from 350 g·min<sup>-1</sup> to 450 g·min<sup>-1</sup> its widening by 0.04 mm (Table 3).

Table 3. The kerf width in dependence on the abrasive mass flow for various tree species

Tree species	Abrasive mass flow (g·min <sup>-1</sup> )	Average value of kerf width	
		top kerf width (mm)	bottom kerf width (mm)
Norway spruce	250	1.05	1.13
	350	1.07	1.19
	450	1.10	1.21
Pedunculate oak	250	1.07	1.97
	350	1.12	1.86
	450	1.14	1.73
European beech	250	1.16	1.66
	350	1.13	1.45
	450	1.19	1.36

The influence of abrasive mass flow on the kerf width on the output side of AWJ from material is directly opposite (Fig. 9). An increase of abrasive mass flow from 250 g·min<sup>-1</sup> to 350 g·min<sup>-1</sup> causes the narrowing of the kerf by 0.09 mm on average and an increase of abrasive mass flow from 350 g·min<sup>-1</sup> to 450 g·min<sup>-1</sup> its narrowing by 0.07 mm (Table 3).

The clarification of this phenomenon is identical with the influence of feed rate, because an increase in abrasive mass flow quantity is its analogy.

The increase of abrasive mass flow was caused by a higher amount of abrasive particles falling on the unit length of cutting path. A greater amount of particles has much more energy at its disposal, which is able to take off much more material from the point of cutting.

It causes the widening of the kerf on the input side of AWJ into material and, on the contrary, its narrowing on the output side of AWJ from mate-

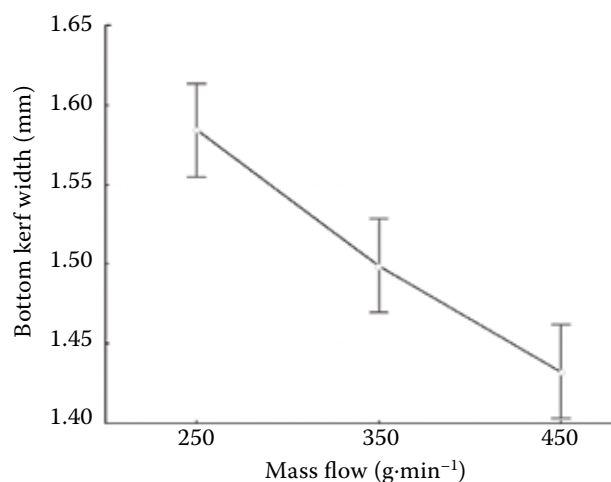


Fig. 9. Influence of the abrasive mass flow on kerf width on the output side of AWJ from material

rial. The explanation of this phenomenon lies in the fact that much more abrasive particles pass through the given point, but the energy of these particles is gradually utilized for cutting and its increase in the given space is manifested by a decrease of water-jet lagging and not by a further widening of the kerf width.

## CONCLUSION

By proper choice of feed rate and abrasive mass flow it is possible to influence the kerf width on the side of AWJ input into material and also on the side of AWJ output from material, as well as the mutual relationship of these two widths.

In principle it can be claimed that a decrease of the feed rate leads to a widening of the kerf width on the side of AWJ input into material and, on the contrary, to its reduction on the side of AWJ output from material.

From the practical viewpoint we are considering the model situation from a theoretical analysis of the problems. In case that we are cutting the 25 mm thick beech sawn timber under technological conditions of the feed rate of  $0.6 \text{ m} \cdot \text{min}^{-1}$  and abrasive mass flow of  $450 \text{ g} \cdot \text{min}^{-1}$ , in cutting along the grains the kerf width on the input side of AWJ is 1.13 mm, and across the grains it is 1.27 mm. By changing the feed rate to  $0.4 \text{ m} \cdot \text{min}^{-1}$ , the change of the kerf width in cross cutting on the input side of AWJ into material will be 1.13 mm. In the case of flat sawn-timber, the kerf width on the input side of AWJ into material is 0.91 mm, and across the grains it is 1.03 mm; by changing the feed rate to  $0.2 \text{ m} \cdot \text{min}^{-1}$  and the abrasive mass flow to  $250 \text{ g} \cdot \text{min}^{-1}$ , the change of the kerf width on the side of AWJ input into material will be 0.91 mm.

## References

- BARCÍK Š. (2007): The progressive method of wood machining by water jet. In: SIKLIENKA M. (ed.): Woodcut Tools and Woodworking 2007. Zvolen, 13. December 2007. Zvolen, Technická univerzita vo Zvolene: 3–11. (in Slovak)
- BEER P. (2007): Unconventional Tools for Woodworking. Poznań, Wydawnictwo Akademii Rolniczej: 58–70. (in Polish)
- ENGEMANN BERND K. (1993): Water Jet and Laser Radiation Cutting. Berlin, Ehningen bei Böblinger: 53–93. (in German)
- GERENCSÉR K., BEJÓM L. (2003): Investigations into the cutting of solid wood. FAIPAR, **54**: 32–45.
- HASHISH M. (1991): Optimalization factors in abrasive waterjet machining. Journal of Engineering for industry. **113**: 29–37.
- HAVLÍK B. (1995): Quantification of Process Parameters for Water Jet Machining. Bratislava, KVT SJF STU: 1–69. (in Slovak)
- KMINIAK R. (2010): Native Wood Working by Abrasive Water. [PhD. Thesis.] Zvolen, Technická Univerzita in Zvolen: 1–124. (in Slovak)
- KMINIAK R., BARCÍK Š. (2011): Influence of the chosen technical and technological and material parameters of the jet lagging during the process of native wood cutting by abrasive water jet. In: BARCÍK Š., DVOŘÁK J. (eds): Woodworking Techniques 2011. Prague, 7.–10. September 2011. Prague, Czech University of Life Sciences in Prague: 153–161.
- KMINIAK R., BARCÍK Š., KVIETKOVÁ M. (2011): Effect of material properties of solid wood cutting width of joints in abrasive water jet cutting. Acta Facultatis Xylogologiae Zvolen, **53**: 43–53.
- KRAJNÝ Z. (1998): Waterjet in Practice. Bratislava, EPOS: 10–250.
- KULEKCI M. K. (2002): Processes and apparatus developments in industrial waterjet applications. International Journal of Machine Tools and Manufacture, **42**: 1297–1306.
- LISIČAN J. (1996): Theory and Technology of Wood Processing. Zvolen, Matcentrum: 427–428. (in Slovak)
- MAŇKOVÁ I. (2000): Progressive Technologies. Košice, VIE-NALA: 63–90. (in Slovak)
- MATUŠKA J. (2003): Materials cutting by waterjet. Strojárstvo, **11**: 35. (in Slovak)
- REISNER J. (2004): Presents in water jet and laser cutting in the wood industry in the CR. In: DZURENDA L. (ed.): Chip and Chipless Woodworking. Starý Smokovec-Tatry, 4.–16. October 2004. Zvolen, Technická Univerzita in Zvolen: 201–204. (in Slovak)

Received for publication July 18, 2011

Accepted after corrections September 29, 2011

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*Corresponding author:*

Doc. Ing. ŠTEFAN BARCÍK, CSc., Czech University of Life Sciences in Prague, Faculty of Forestry and Wood Sciences, 165 21 Prague 6-Suchbát, Czech Republic  
e-mail: barcik@fld.czu.cz

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