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Water Jet Interaction within Material Cutting Processes

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Abstract: *Water Jet Interaction within Material Cutting Processes.* The article is dealing with the issue of aglomerated materials (chipboards and fiberboards) cutting by an abrasive water jet at the pressure of 400 MPa with abrasive agent (GMA Australian garnet, 80 MESH grain) and its impact on its cutting gap width. The experiment was carried out at feed speeds of 0.2, 0.4 and 0.6 $m.min^{-1}$ and the abrasive agent mass flow of 250 $g.min^{-1}$, 350 $g.min^{-1}$ and 450 $g.min^{-1}$. The results indicate the energy potential of the abrasive water jet. Based on the results, an optimum feed speed of 0.4 $m.min^{-1}$ and the abrasive agent optimum mass flow rate of 450 $g.min^{-1}$ can be determined for the aglomerated materials cutting.

Keywords: abrasive water jet, abrasive agent mass flow rate, feed speed

INTRODUCTION

For efficient, environment-friendly and quick processing of wood and materials based thereon, appropriate processes are necessary (Gaff and Gáborík, 2009). The cutting by the mean of water jet is one of such processes. The water jet cutting is based on same principle as the water erosion (Bernard, 1993). It is clean, generating not even fine scrap due to the cutting nor grinding scrap; no chips are generated and not even chemical contamination of atmosphere takes place (Kminiak and Gaff, 2014).

The water jet or stream, which represents the cutting tool in this process, is flowing under high pressure throughout the nozzle low-diameter orifice (usually about 0.3 mm) while bearing high kinetic energy (Kminiak and Gaff, 2014). As far as the kinetic energy effect on given material concerns, the liquid jet could be viewed as even a "solid" body (Gaff, et. al., 2010).

During the liquid jet contact with the surface of material to be cut, the kinetic energy accumulated in the liquid jet is released and acting on the material. This is indicated by dramatic tension increase in the contact zone until the material is broken (Maňková, 2002, Gaff and Zemiar, 2006).

For the processing of soft materials, clear water jet is used normally; an abrasive (hydroabrasive) jet shall be used in the other cases. As an abrasive agent is suitable, for instance, garnet; this is chosen in function of the hardness of the material to be cut. The abrasive material hardness vs. cut material hardness ratio is important. The most known type of abrasive agent is the sorted quartz sand, garnet, fine aluminum oxide or ice particles forming so-called cryogenic water jet (Krajný, 1998). The cutting head movement, and thereby the entire cut course, are controlled by a preset computer software (Gaff and Zemiar 2008).

The material cutting by the mean of water jet has wide range of industrial applications. It is an excellent alternative of traditional methods of material cutting whenever no material deformations caused by the cutting are allowed. The combination of water high pressure and abrasive agent allows quick and efficient cutting, boring and drilling of any type of material.

The water jet cutting method for wood and materials based thereon provides a lot of advantages, although there are still some limits and insufficiencies. Therefore, it is subject to investigation and improvement of the process and its applications.

MATERIALS

The proper experiment took places in the premises of the company DEMA spol. s.r.o. with headquarters in Zvolen. DEMA is an owner of water jet manufactured by FLOW Int. and PTV spol. s.r.o. Prague. This is consisting of PTV 37 - 60 Compact high-pressure pump and work bench with WJ 20 30 D -1Z cutting head delivered by PTV.

Tested Samples

- thickness of the test sample: 16 mm / 32 mm / 548mm – Chipwood,
  22 mm/ 44 mm/ 66 mm – fiber boards,
- the required width of the test sample: š = 180 mm (± 2.5 mm),
- required length of the test sample: l = 500 mm (± 5 mm),
- moisture content of the test samples: w = 8% (± 2%).
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Parameters of Cutting Process

- 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.

Methodology of Water Jet Evaluation

Definition of Terms:

$\boldsymbol{w_t}$ - top kerf width: this is the kerf width after the abrasive water jet pass throughout the material, measured on the water jet input side into the material;
$\boldsymbol{w_b}$ - bottom kerf width: this is the kerf width after the abrasive water jet pass throughout the material, measured on the water jet output side from the material.
Measurement procedure:

1. Digital photo of the kerf with reference scale.
2. Measurement of bottom kerf width is becoming more difficult due to the cutting edge corrugated profile. As for the practical applications, the maximum kerf size is important (as far as the determination of allowances for the eventual further machining), the kerf width is measured as a distance of the two most distant parallel tangents of the cut edge. The evaluated cutting edge length was always 15 mm.
3. The conversion of relative dimensions was evaluated according to the following formula:

$$\boldsymbol{w_b = \frac{w_p . a}{a_p}} \quad [\text{mm}] \qquad (1)$$

wb - skutočný rozmer reznej škáry [mm],
wp - pomerný rozmer reznej škáry (rozmer zmeraný v programe Auto CAD na digitálnej fotografii) [--],
a - skutočný rozmer jednotky referenčnej mierky [mm],
ap - pomerný rozmer jednotky referenčnej mierky (rozmer zmeraný v programe Auto CAD na digitálnej fotografii) [--].

4. Evaluation of the measured data.

RESULTS

Based on the evaluation of the measured data, the following resulted for the influence of feed speed and abrasive agent mass flow rate on the kerf width for fiber- and chipboards.

Feed Speed Influence

While increasing the feed speed from 0.2 to 0.4 m.min^{-1}, the AWJ kerf width decreased by 0.13 mm; at the feed speed increase from 0.4 to 0.6 m.min^{-1}, the AWJ kerf width decreased again.

Table 1. Feed speed influence on the AWJ top kerf width for fiber-based materials

Feed Speed (m.min^{-1})	0,2	0,4	0,6
The average value of the width of the cut joints (mm)	1,36	1,23	1,01
Standard error (mm)	0,01	0,01	0,01
- 95,00 % (mm)	1,25	1,18	0,89
+95,00% (mm)	1,68	1,42	1,14

Table 2. Feed speed influence on the AWJ bottom kerf width for fiber-based materials

Feed Speed (m.min^{-1})	0,2	0,4	0,6
The average value of the width of the cut joints (mm)	1,48	1,56	1,99
Standard error (mm)	0,03	0,03	0,03
- 95,00 % (mm)	1,32	1,45	1,87
+95,00% (mm)	1,75	1,73	2,12

When changing the feed speed from 0.2 to 0.4 m.min^{-1} on the AWJ output from the fiber-based material, the bottom kerf width increased; similar effect occurred also at the feed speed change from 0.4 to 0.6 m.mim^{-1}, where the AWJ bottom kerf width values also increased.

Table 3. Feed speed influence on the AWJ top kerf width for chip-based materials

Feed Speed (m.min^{-1})	0,2	0,4	0,6
The average value of the width of the cut joints (mm)	1,68	1,49	1,35
Standard error (mm)	0,01	0,01	0,01
- 95,00 % (mm)	1,53	1,33	1,12
+95,00% (mm)	1,79	1,65	1,54

Table 4. Feed speed influence on the AWJ bottom kerf width for chip-based materials

Feed Speed (m.min^{-1})	0,2	0,4	0,6
The average value of the width of the cut joints (mm)	1,72	1,89	2,13
Standard error (mm)	0,03	0,03	0,03
- 95,00 % (mm)	1,61	1,75	1,92
+95,00% (mm)	1,86	1,98	2,27

Based on the results shown in Tables 1 to 4, it is possible to conclude that analogous effect took place for both top and bottom kerf widths of the abrasive water jet at chip-based materials. The top kerf width was decreasing and the bottom kerf width was increasing with the feed speed change.

Influence of Abrasive Agent Mass Flow Rate

The AWJ lag average value was changing with gradual change of the thickness. When the thickness increased from its minimum to its maximum, the lag value was increasing.

Table 5. Abrasive agent mass flow rate influence on the AWJ top kerf width for fiber-based materials

The mass flow of abrasives (g.min^{-1})	250	350	450
The average value of the width of the cut joints (mm)	1,27	1,28	1,29
Standard error (mm)	0,01	0,01	0,01
- 95,00 % (mm)	1,01	1,09	1,10
+95,00% (mm)	1,41	1,47	1,50

Table 6. Abrasive agent mass flow rate influence on the AWJ top kerf width for fiber-based materials

The mass flow of abrasives g.min^{-1})	250	350	450
The average value of the width of the cut joints (mm)	1,64	1,52	1,41
Standard error (mm)	0,09	0,09	0,09
- 95,00 % (mm)	1,51	1,45	1,29
+95,00% (mm)	1,79	1,63	1,56

In case of change of the added amount of the abrasive agent from 250 to 350 g.min^{-1} for the fiber-based materials cutting, the top kerf width values increased by 0.01 mm, and subsequently, after increasing the amount of the abrasive agent to 450 g.min^{-1}, further increase was observed.

For the bottom kerf width of the water jet, the change of the abrasive agent amount from 250 to 350 g.min^{-1} resulted in a decrease; the same shall apply for the change of the abrasive agent amount from 350 to 450 g.min^{-1}.

Table 5. Abrasive agent mass flow rate influence on the AWJ top kerf width for chip-based materials

The mass flow of abrasives (g.min^{-1})	250	350	450
The average value of the width of the cut joints (mm)	1,36	1,41	1,49
Standard error (mm)	0,01	0,01	0,01
- 95,00 % (mm)	1,14	1,09	1,10
+95,00% (mm)	1,52	1,47	1,50

Table 6. Abrasive agent mass flow rate influence on the AWJ top kerf width for chip-based materials

The mass flow of abrasives (g.min^{-1})	250	350	450
The average value of the width of the cut joints (mm)	1,59	1,48	1,39
Standard error (mm)	0,09	0,09	0,09
- 95,00 % (mm)	1,42	1,36	1,15
+95,00% (mm)	1,67	1,58	1,46

The top kerf width decreases at the increase of the abrasive agent mass flow rate from 250 to 350 g.min^{-1}. On the other hand, when changing the abrasive agent mass flow rate to 450 g.min^{-1}, the kerf width is increasing. For the AWJ bottom kerf width at chip-based materials, the effect was opposite to that for the AWJ top kerf width.

Based on the experiment, the feed speed of 400 $mm.min^{-1}$ was found as the optimum one, since it is at this value when both top and bottom kerf widths achieve the minimum dimensions.

When increasing the abrasive agent mass flow rate to 450 $g.min^{-1}$, the kinetic energy of the particles is consumed by their mutual contact; this caused the secondary effect of the material washout on the input and the subsequent narrowing of the bottom kerf width due to the energy loss. However, when comparing the values uniformity on both top and bottom, the abrasive agent mass flow rate of 450 $g.min^{-1}$ is becoming the optimum value.

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Streszczenie: *Interakcja strumienia wody w procesie cięcia materiału.* Artykuł dotyczy problematyki materiałów aglomerowanych (płyta wiórowa i pilśniowa) ciętych strumieniem wody o ciśnieniu 400 Mpa z dodatkiem ścierniwa i jego pływu na szerokość razu. Eksperyment przeprowadzono przy prędkościach posuwu 0.2, 0.4 i 0.6 $m.min^{-1}$ oraz przepływie ścierniwa 250 $g.min^{-1}$, 350 $g.min^{-1}$ oraz 450 $g.min^{-1}$. Eksperyment wykazł że optymalną prędkością posuwu dla cięcia tych materiałów jest 0.4 $m.min^{-1}$ przy przepływie ścierniwa 450 $g.min^{-1}$.

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