Topography of material made by the application of abrasive water jet technology

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ABSTRACT: Water jet cutting technology is widely applicable in all industrial areas in areas where the need for high dimensional precision machined material. Quality of surface corresponds to the scale from middle smooth milling to rough milling. It shows the results of undulation in dependence on technical and technological parameters – feed rate and abrasive mass flow. The paper also contains the methodology for assessment of the effect of these parameters on surface finished undulation. Our paper presents significant results of experiments made by this methodology applied to MDF, OSB boards and to technical beech plywood. We can see from the above-mentioned results that the fundamental indicator for roughness assessment is the arithmetical mean deviation of roughness profile R_a. MDF boards have the most homogeneous structure in the entire cut among the monitored materials, which affects the insignificance of parameter $R_{a.}$ For OSB boards, we can see the worse surface quality with higher feed rate and vice versa for plywood, higher feed rate improves the surface quality. A higher amount of abrasive flow causes the worse surface quality.

Keywords: abrasive flow; feed rate; cutting by abrasive water jet

A possibility of Abrasive Water Jet (AWJ) utilization is determined by various input factors and also by the quality requirements for the final product. AWJ can be used for the cutting of metal materials, and also for the manufacturing in the wood-processing industry. Therefore the know-how for the parameter which characterizes the geometric and shape accuracy of cutting surface is very important. It is mainly about roughness, wave shapes, shape surface deflection. All these are parameters which describe the topography of cutting surface, created by the application of AWJ technology (Beer 2007).

Elimination of particular deficiencies within the practical use of AWJ in the wood industry is the goal of our paper which presents the results from an experimental investigation of the influence of selected technological and material factors on the arithmetical deviation mean (R_a) as an indicator representing the surface finished undulation of manufactured agglomerated materials. The principle of water jet machining technology can be easily explained as removing material by mechanical impacted fluid on the workpiece (Engemann 1993). Water jet technology is one of the latest untraditional industrial methods used for manufacturing/cutting. Two practical methods of water jet manufacturing/cutting are used: pure Water Jet (WJ) and AWJ. They have both unique properties for an industrial application. Cutting power is reached by the transformation of hydrostatic energy (400 MPa) into the stream with sufficient kinetic energy (almost 1,000 $m \cdot s^{-1}$) (Hashish 1993; Kulekci 2002).

The nature of material breach by the water jet is based on the principle that the beam – a tool moving at a speed rate (max. 885 $m \cdot s^{-1}$ at a pressure of 400 MPa), can be seen as a solid body from the viewpoint of its effect. Disruption of the material is a result of transformation of the input energy of continuous drop flow – the beam into the material. The input energy causes a tension in a very small area (e.g. the beam of 0.3 mm in diameter represents an area of 0.07 mm^2), which leads to deformation of the original structure and removing of a certain volume of material. Water jet with abrasive ranks among many wedge tools with undefined cutting edge (like grinding) and also the basic mechanism of material removing is similar to the above-mentioned method. Cutting wedges are formed with abrasive grains randomly oriented in the beam. The quality of the surface should meet the quality of flat milling. This is the requirement for AWJ application as a final operation of surface finishing. From the viewpoint of surface quality milling can be divided into smooth milling, middle smooth milling and rough milling (Öjmerts, Amini 1994; Kalpakjian 1995).

Clean water after chemical and mechanical processing is used without added mechanical particles. The properties of water at high pressures (water pressure around 400 MPa) are fully used as a cutting tool (Havlik 1995; Maňková 2000). When hard and tough materials are machined or when it is required to increase cutting efficiency, the water jet is replenished by abrasive grains. This kind of method is called abrasive water jet machining (Krajný 1998; Gerencsér, Bejo 2003).

It is a very simple, clean and reliable technology and therefore it becomes an alternative to other methods in various branches. But there are also limitations of WJC and therefore its technological process should be monitored and improved.

MATERIAL AND METHODS

During the experiment samples of agglomerated materials were used where:

– the thickness of the test sample: 22 × 44 × 66 mm MDF (medium density fibreboard), 16 × 32 × 48 mm OSB (oriented strand board), 18 × 36 × 54 mm plywood,
– the required width of the test sample: *w* = 180 mm (± 2.5 mm),
– the required length of the test sample: *l* = 500 mm (± 5 mm),
– the moisture content of the test samples: w = 8% (± 2%).

Cutting of samples was done in DEMA Ltd. in Zvolen. The equipment was assembled on the basis of components of the American Company FLOW Int. (PTV Ltd., Praha, Czech Republic) (Fig. 1). It consists of a high-pressure pump PTV 37-60 Compact (PTV Ltd., Praha, Czech Republic), and a work table with water-jet head WJ 20 30 D-1Z (PTV Ltd., Praha, Czech Republic).

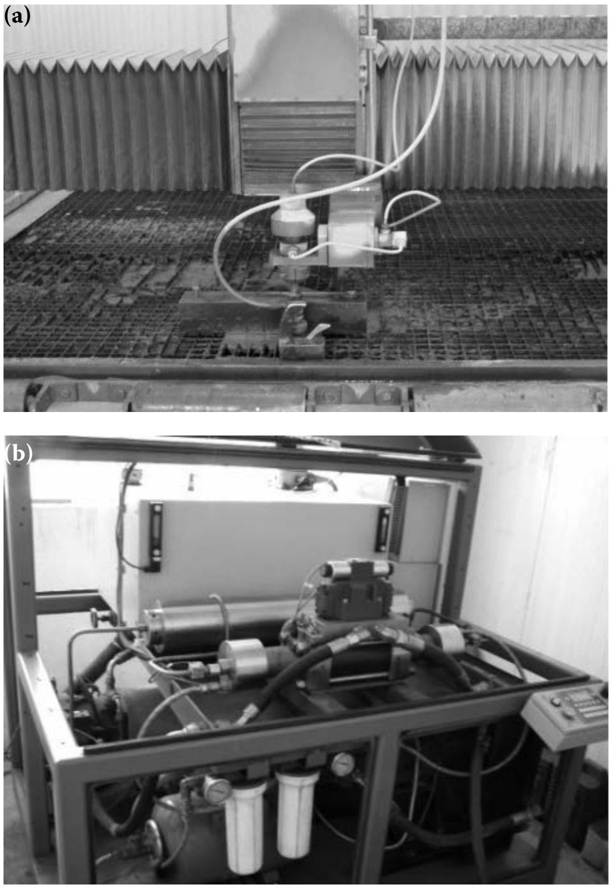

Fig. 1. Technological equipment for cutting by DEMA Ltd. water jet: (a) work-table of the equipment (b) high-pressure pump (multiplier)

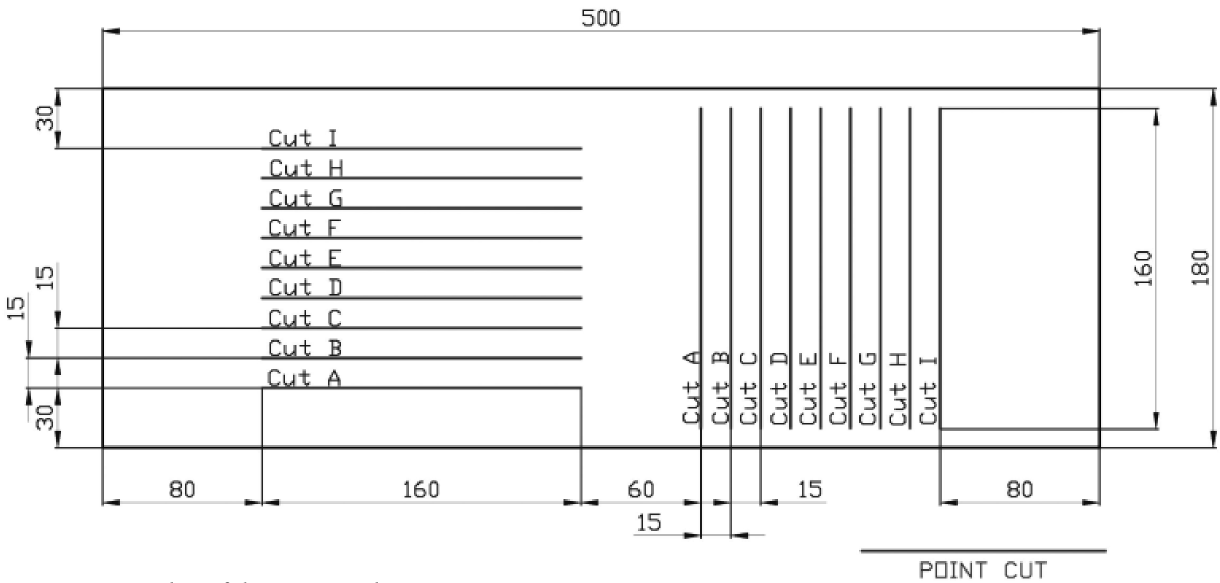

Fig. 2. Cutting plan of the test sample

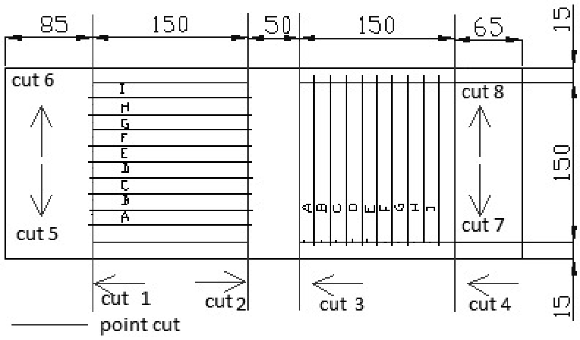

Fig. 3. Cutting plan of samples

Working cuts were performed on three samples for each thickness in order to eliminate the impact of specific characteristics of the sample (Fig. 2).

Technical parameters of the devices are similar. The experiments were realized with technical parameters of the equipment:
– cutting liquid pressure: 4,000 bar = 400 MPa
– abrasive: Australian garnet GMA (grain size 80 MESH = 0.188 mm)
– diameter of abrasive jet nozzle: 1 mm
– diameter of water jet: 0.013 inch = 0.33 mm
– distance of the jet nozzle above the workpiece: 4 mm

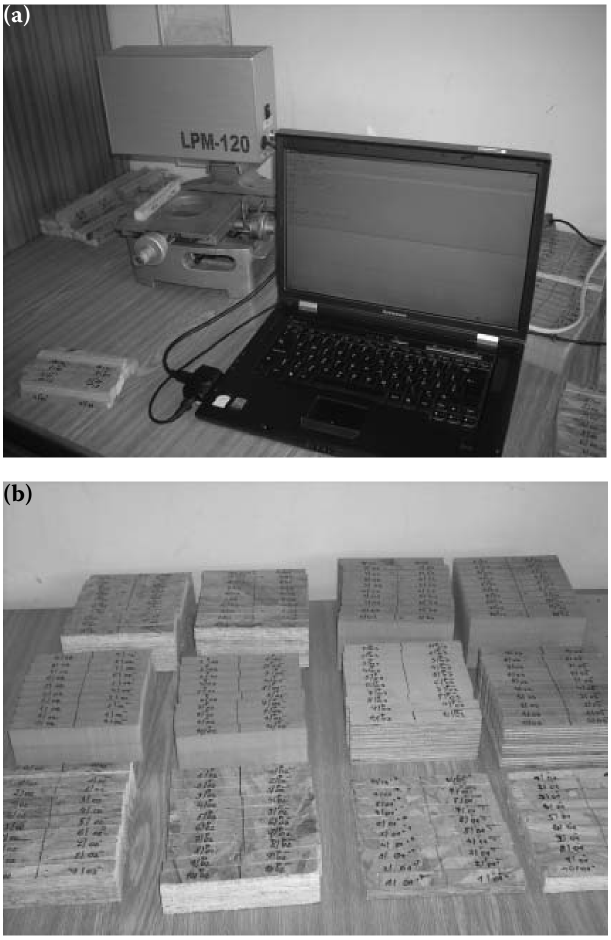

Fig. 4. Measurement of surface roughness and related tested samples

– abrasive mass flow: m_a = 250/350/450 g·min^{-1}
– feed rate: v_f = 0.2/0.4/0.6 mm·min^{-1}

Working steps: the working sample was further divided into particular parts according to the following cutting plan (Fig. 3) (Kvietková 2011).

Definition of measured indicator. R_a – arithmetical mean deviation of profile abrasiveness: it means the arithmetical mean level of absolute profile deviations within the basic length, measured on the abrasiveness profile (in the profile implied from the primary profile by the elimination of parts with long wavelength) During the experiments the relevant parameter R_a was monitored (Fig. 4).

Procedure of measuring. The sample in laser profilometer was oriented in such a direction that it was possible to measure the roughness of the processed surface in a given track (the measured place is marked by laser light, Fig. 4). Conditions:
– all tracks were parallel to the lateral edge of the sample,
– the first track was 5 mm from the lateral edge of the sample,
– every further track was shifted by 5 mm,
– the last track was 5 mm from the opposite lateral edge of the sample,
– tracks were centred into the middle of the sample length.

Tracks of measurement represent places in the height of the sample where the measurement was done. The given system of measurements is under context with 3 cutting zones of AWJ. The first zone is so called zone of cutting erosion; the second zone is zone of deformation erosion of the material and the third zone is the zone of material which is not cut through the whole thickness.

RESULTS AND DISCUSSION

During the experiment the arithmetical mean deviation of the profile was monitored and evaluated and further it was statistically processed by the analysis of variance.

MDF boards

We can see from the analysis of variance for MDF – that all monitored factors are statistically insignificant (Table 1).

MDF boards have the most homogeneous structure in the entire cut among the monitored materials, which affects the insignificance of parameter $R_{a.}$

Table 1. Final results from the analysis of variance of arithmetical mean deviation R_a

	Sum of squares	Degrees of free-dom	Vari-ance	*F*	*P*
MDF boards					
Intercept	2.643	1	2.643	1.010	0.315287
Feed rate	5.233	2	2.616	1.000	0.368578
Abrasive flow	5.232	2	2.613	0.999	0.368669
OSB boards					
Intercept	56,946.32	1	56,946.32	17,687.6	0.000000
Feed rate	4.56	2	2.28	0.71	0.014929
Abrasive flow	93.50	2	46.75	14.52	0.000001

OSB boards

The measured set of arithmetical mean deviations R_a was processed by multifactorial analysis of variance (Table 1).

Feed rate. Feed rate has an important impact on surface roughness. The average level of arithmetical deviations R_a varied according to the feed rate (Fig. 5).
– arithmetical mean deviation decreased to 0.23 μm* when the feed rate changed from 0.2 to 0.4 m·min^{-1},
– arithmetical mean deviation increased to 0.08 μm* when the feed rate changed from 0.4 to 0.6 m·min^{-1}.
*The given value corresponds to Table 2.

With an increase in the feed rate from 0.4 to 0.6 m·min^{-1} roughness also increased, which negatively impacted the surface quality. The given effect can be described that with the increased feed rate, the cutting tool has to dismantle more material, which decreases the surface quality. It is caused by the higher uprooting of fibres from the cutting material.

Abrasive flow. Arithmetical mean deviation R_a changed according to the amount of abrasive flow as it is given below (Fig. 5):

Table 2. Arithmetical mean deviations of surface roughness R_a (μm) according to a shift of the feed rate for OSB board

	Average value	Limit	
		lower	upper
Feed rate (m·min^{-1})			
0.2	10.39078	10.17611	10.60545
0.4	10.16863	9.90408	10.43318
0.6	10.24814	9.83625	10.66004
Abrasive flow (g·min^{-1})			
250	9.95729	9.69296	10.22161
350	9.99298	9.69157	10.29439
450	10.85729	10.51926	11.19531

– during the change of abrasive flow from 250 to 350 g·min^{-1}, the change of deviation was only 0.04 μm*,
– during the change of abrasive flow from 350 to 450 g·min^{-1}, the change of deviation increased to 0.86 μm*.
*The given value corresponds to Table 4.

Table 3. Summary results of the analysis of variance for arithmetical mean deviation R_a for plywood

	Sum of squares	Degrees of free-dom	Variance	*F*	*P*
Intercept	64,341.63	1	64341.63	16232.7	0.000000
Feed rate	14.45	2	2.616	8.35	0.000271
Abrasive flow	0.86	2	2.613	1.82	0.162458

By increasing the abrasive flow the surface roughness is also increasing and therefore quality is decreasing. It is caused by a higher amount of removed material by the tool with the higher value of abrasive flow. There are more abrasive particles in the kerf, which impacts increasing roughness and therefore further quality decreasing of surface material accord-

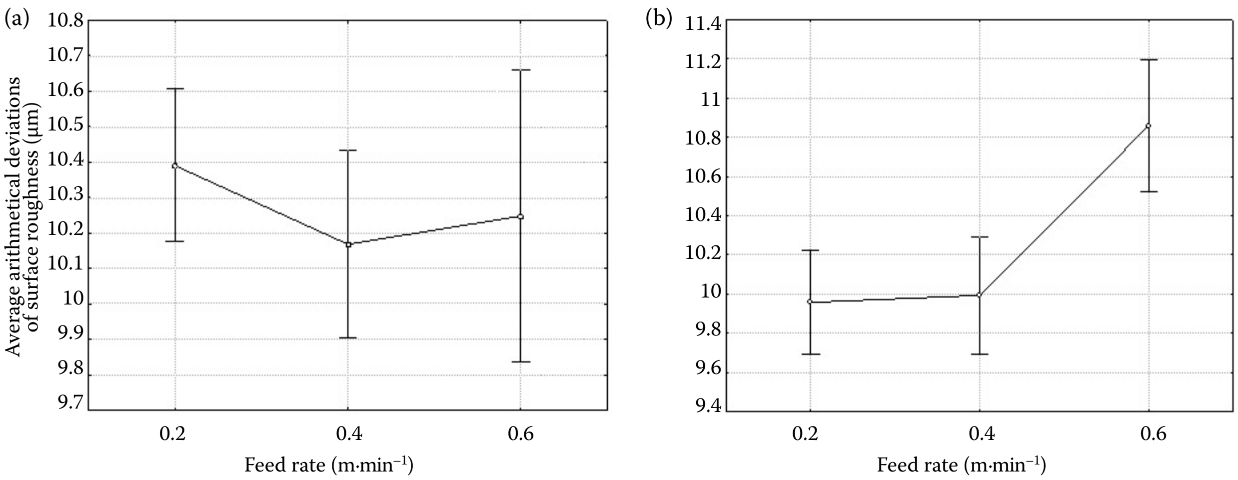

Fig. 5. Effect of feed rate (a), abrasive flow (b) on arithmetical mean deviation for OSB boards

Table 4. Arithmetical mean deviations R_a according to feed rate for plywood

	Average value	Limit	
		lower	upper
Feed rate ($m \cdot min^{-1}$)			
0.2	11.33597	11.02681	11.64512
0.4	10.99371	10.68456	11.30287
0.6	10.48278	10.17450	10.79107
Abrasive flow ($g \cdot min^{-1}$)			
250	10.96342	10.68586	11.24097
350	11.11900	10.79985	11.43815
450	10.72274	10.34890	11.09658

ing to natural decomposition of AWJ. It is a similar effect like in the feed rate.

Technical beech plywood

Results of all experiments for plywood are presented in Tables 3 and 4, and in Fig. 6.

Feed rate. Multifactorial analysis of variance confirmed that abrasive flow is a statistically insignificant parameter. R_a changed according to the feed rate **(**Fig. 6):

– arithmetical mean deviation decreased to 0.23 μm* when the feed rate changed from 0.2 to 0.4 $m \cdot min^{-1}$*,
– arithmetical mean deviation increased to 0.08 μm* when the feed rate changed from 0.4 to 0.6 $m \cdot min^{-1}$*.

*The given value corresponds to Table 4.).

It was confirmed that with the increasing feed rate arithmetical mean deviation of roughness R_a decreased. The quality of the material surface increased. During the cutting of technical beech plywood wood elements are more easily removed, which causes smaller surface destruction and it also has a smaller impact on the roughness of the surface.

Abrasive flow. R_a changed according to the change of abrasive flow as follows (Fig. 6):

– during the change of abrasive flow from 250 to 350 $g \cdot min^{-1}$, deviation R_a increased only to 0.15 μm*.
– during the change of abrasive flow from 350 to 450 $g \cdot min^{-1}$, deviation R_a decreased to 0.39 μm*. This parameter is statistically insignificant.

*The given value corresponds to Table 4.

The value of arithmetical mean deviation is statistically insignificant for this material. Plywood is very similar in the structure and characteristics to native raw wood because the surface is composed of cutting planes which are made by the cutting tool and the amount of abrasive flow does not change its size but only its amount.

DISCUSSION

According to Junkari et al. (2006) the increasing feed rate leads to an increase in surface roughness, which is comparable with our results. Vikram et al. (2002) described a negative impact of the increasing rate on the quality of the machined surface. We also presented it for the OSB material. In the plywood and MDF, this factor is insignificant as it was also reported in the study of Hashish (1991) and Kalyanasundarama et al. (2008), who also confirmed these facts. The increase of abrasive flow leads to deterioration of the machined surface due to exposure to larger amounts of abrasive particles in the cut, which was also revealed by the research of Plessis and Hashish (1978) and Hascalika et al. (2007). This fact can be explained by the homogeneous structure of the material.

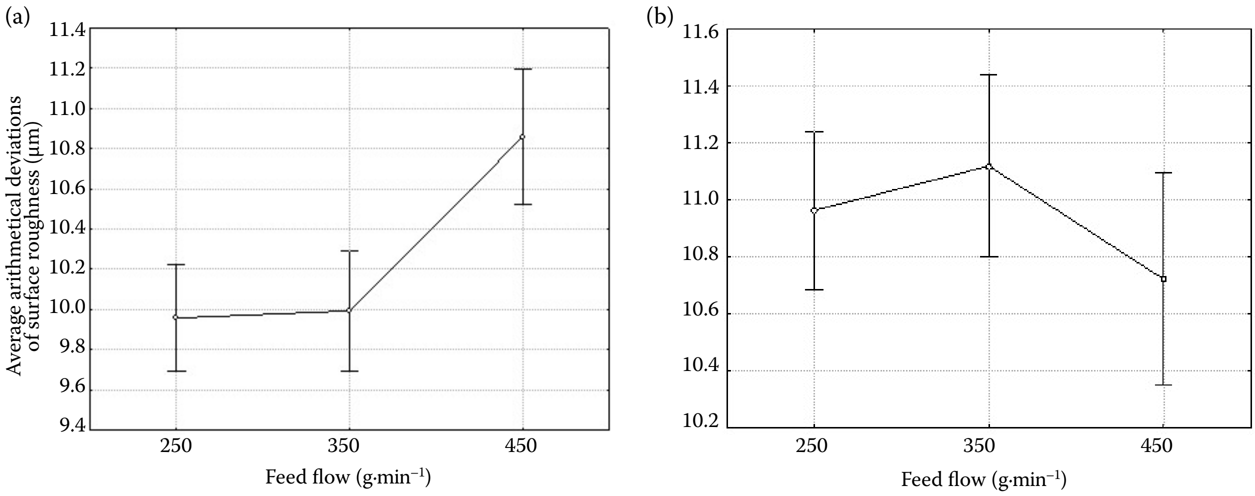

Fig. 6. Effect of feed rate (a), abrasive flow (b) arithmetical mean deviation for plywood

CONCLUSIONS

The quality of the surface is given by its undulation which is created during material processing and manufacturing. The quality of the surface corresponds to the scale from middle smooth milling to rough milling. The monitoring of surface roughness is the most frequently used method for surface quality assessment.

We can see from the above-mentioned results that the fundamental indicator for roughness assessment is arithmetical mean deviation of roughness profile R_a. MDF boards have the most homogeneous structure throughout the entire cross-section and therefore these boards were evaluated as statistically insignificant material.

The impact of feed rate on OSB boards and plywood was a statistically significant parameter. For OSB boards, we can see the worse surface quality with higher feed rate and vice versa for plywood, higher feed rate improves the surface quality. From the above-mentioned we can say that R_a for OSB is higher and for plywood this indicator is lower.

The impact of abrasive flow seems to be a statistically significant parameter only for plywood. The higher the amount of abrasive flow, the higher the values of R_a. A higher amount of abrasive flow causes the worse surface quality (this statement does not match for MDF boards and plywood because this factor is statistically insignificant for them).

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