THE ASSESSMENT OF PROPERTIES FOR SELECTED FACTORS IN ABRASIVE WATER JET PROCESS

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Abstract
The article presents the current conditions of abrasive water jet cutting process and factors relative to the quality of cutting surface. The main goal of research was to evaluate the assessment of the cutting depth, corrugated bottom cutting edge and roughness of the specimens depending on selected factors such as cutting speed and abrasive amount in the abrasive water jet process. Specimen were cut in four phases as a square. Main results were that the distance between water jet entering and water jet leaving is decreased with the increasing abrasive amount and by following lower cutting rates. The increasing of a cutting rate negatively effects the quality of the cut surface and the size of the distance between water jet entering and water jet leaving, because the increasing of a cutting rate increases also values of the mentioned parameters. As to the distance between water jet entering and water leaving, the abrasive amount of 200-250 $g.min^{-1}$ at the rate of 50 $mm.min^{-1}$ is considered to be optimal, but outside this range the influence of the abrasive amount impacts negatively, primarily on water jet entering and water jet leaving that has a direct influence on the corrugated bottom cutting edge.

Keywords: surface structure, abrasive water jet, cutting process.

1 Introduction

The main aim of this research was to analyse the influence of selected factors to the final quality of the surface cut by the abrasive water jet. To achieve this aim it was necessary to evaluate the total cutting depth (longest beam impact), corrugated bottom cutting edge and roughness by changing the cutting speed and the amount of abrasives to be used. Also it was very necessary to choose appropriate material to suggest the suitable size and shape of specimen, to propose the process of specimen production, methodology of evaluating quality surface, to carry out measurability for the purpose of evaluating the quality of surface and to determine the model dependencies between cutting speed, amount of abrasives and final quality [1, 2].

2 Experimental materials and procedures

Test material for specimens used in the research was represented by stainless material AISI 304. This material is stainless (CrNi) and represents the second most frequently used material

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because it has very high resistance to corrosion. Abrasive that was selected is, at the present time, the most frequently used garnet (Bengal Bay Garnet). It is non-metal abrasive material fulfilling all ISO 11126 requirements, and it is pure garnet in its homogeneous crystal structure of long operating life and without any silicosis risks [2, 3]. On the basis of information gained about jets and flows used, a test form a x a of a test specimen made of the material AISI 304 and having these dimensions - depth: 15 mm, sides a=35 mm - has been proposed (**Fig. 1**). The specimens were cut in four phases: Phase 1 - perforation of a specimens, Phase 2 - 10 mm length cut from the perforation point (for the measurement of the cut boundary), Phase 3 - specimens cutting in the shape of a square (sides marked as a, b, c, d), Phase 4 - each edge is cut at a different cutting speed (a=50 $mm.min^{-1}$, b=75 $mm.min^{-1}$, c=100 $mm.min^{-1}$, d=125 $mm.min^{-1}$).

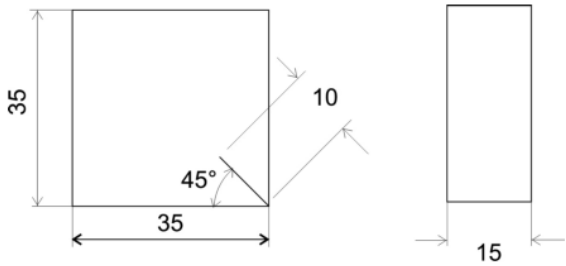

Fig. 1 Specimen 35x35x15 mm, cutting direction of individual sides +y (a), +x (b), -y (c), -x(d)

64 specimens were cut altogether and all diameters were written down into a collecting register of test specimens cutting. 16 specimens out of the total amount of 64 have been chosen for the purposes of this study. Quality degrees of the surface topography are in **Table 1** [1]:

Table 1 Quality grades of the evaluated surface [1]
(*Ra_{HK} – roughness in the top outline, **Ra_{DK} – roughness in the bottom outline)

grade	characteristic	roughness RaHK*	roughness RaDK**
G1	dividing cut	4.0 – 6.3	≤ 40
G2	rough cut	≤ 4.0	≤ 25
G3	middle cut	≤ 4.0	≤ 12.5
G4	quality cut	≤ 3.2	≤ 6.3
G5	high quality cut	< 3.2	≤ 3.2

Factors describes the surface cut by abrasive water jet (surface of the cut) depending to the quality and productivity of abrasive water jet are intended in three categories [4, 5]. Category of basic physical properties, category of the technical factors influence effecting the abrasive water jet erosion process. Analysis of these factors and dimensioning of their optimal setting have an important influence on the quality of the operation of the technological process and the surface made by abrasive water jet.

3 Results and discussion

3.1 Evaluation of the corrugated bottom cutting edge:

During the process of material cutting by the high rate abrasive water jet, the form of the device – water jet - is changed. At a distance of entering the water jet the cut material, the diameter of

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the water jet is expanded and diverted from the originally perpendicular water jet from its own axle [6, 7, 8]. The size of the shape change that cannot be called curvature primarily, depends on the rate of the device movement and the thickness and mechanical properties of the cut material. Energy decrease, resistance of the cut material and the movement rate are the basic factors affecting the characteristic shape of the device (water jet) in cutting material. The curvature of the water jet is made in the opposite direction in comparison to the movement of the cutting head [9, 10]. The increasing of the deflection angle of the leaving water jet against the entering water jet is manifested in the worsening of surface quality that is expressed in the roughness of a new made surface and perpendicularity deflection of the material cut edge in the perpendicular direction to the cutting direction. Position of the area where the water jet enters the processed material is not compatible with the place where the water jet leaves the material. The place of the leaving water jet lags the place of the entering water jet. The lagging of the lower part of the water jet in comparison to the upper part is designated as „jet lag“; in the picture (**Fig. 2**) designated as „L“ [11, 12, 13, 14].

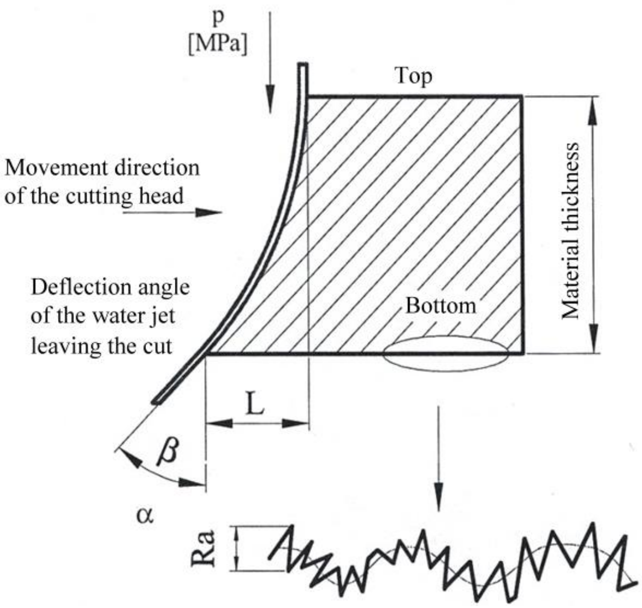

Fig. 2 Trace deflection of cut lag [5]

The size of the jet lag is in the region of tenths of millimetres up to several tens of millimetres and is a natural sign of an economical cutting way [15].
A digital calliper Powerfix Profi has been used to measure and evaluate the intruded length of jet. The specimens has been optically evaluated and the distance has been measured, by means of a calliper, in the most accentuated area of water jet entering and leaving. The values gained have been written down into tables and evaluated by means of graphs [19, 20].
As shown in graph (**Fig. 3**), distance between water jet entering and leaving while using 100 g.min^{-1} amount of abrasive decreased while increased cutting speed. Speed of feed at 125 mm.min^{-1} is the most suitable choice, and cutting speed of 75 mm.min^{-1} is the most inappropriate due to, that corrugated bottom cutting edge is the most visible.

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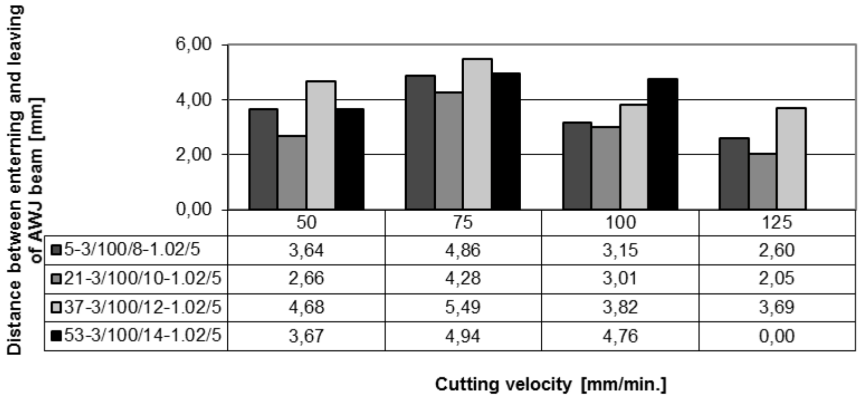
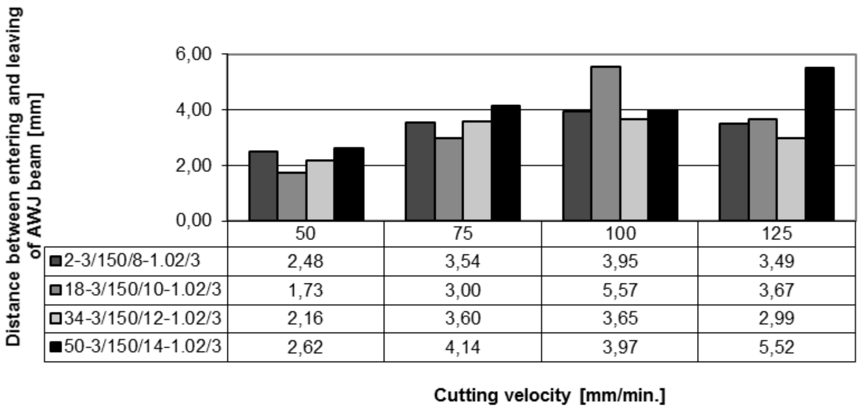


	50	75	100	125
5-3/100/8-1.02/5	3,64	4,86	3,15	2,60
21-3/100/10-1.02/5	2,66	4,28	3,01	2,05
37-3/100/12-1.02/5	4,68	5,49	3,82	3,69
53-3/100/14-1.02/5	3,67	4,94	4,76	0,00

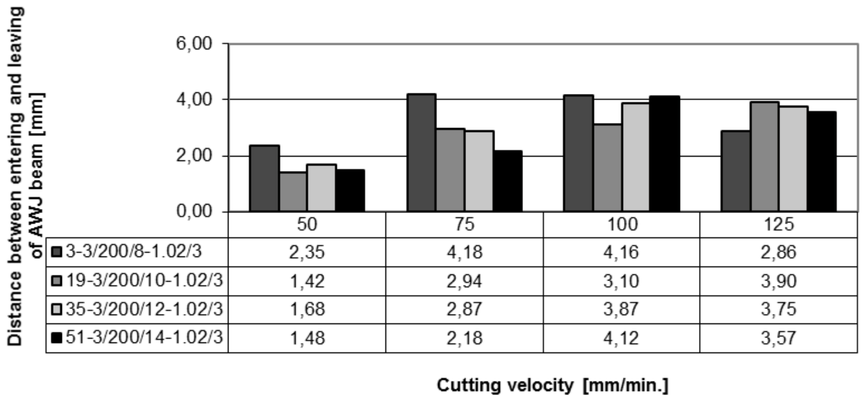
Fig. 3 Evaluation of corrugated bottom cutting edge with abrasive amount of 100g.min^{-1}

As shown in graph (**Fig. 4**), using a constant abrasive amount of 150 g.min^{-1} shows that distance between water jet entering and leaving is the most suitable choice at speed of feed at 50 mm.min^{-1}, and cutting speed of 100 mm.min^{-1} is the most inappropriate due to, that corrugated bottom cutting edge is the most visible.



	50	75	100	125
2-3/150/8-1.02/3	2,48	3,54	3,95	3,49
18-3/150/10-1.02/3	1,73	3,00	5,57	3,67
34-3/150/12-1.02/3	2,16	3,60	3,65	2,99
50-3/150/14-1.02/3	2,62	4,14	3,97	5,52

Fig. 4 Evaluation of corrugated bottom cutting edge with abrasive amount of 150g.min^{-1}



	50	75	100	125
3-3/200/8-1.02/3	2,35	4,18	4,16	2,86
19-3/200/10-1.02/3	1,42	2,94	3,10	3,90
35-3/200/12-1.02/3	1,68	2,87	3,87	3,75
51-3/200/14-1.02/3	1,48	2,18	4,12	3,57

Fig. 5 Evaluation of corrugated bottom cutting edge with abrasive amount of 200g.min^{-1}

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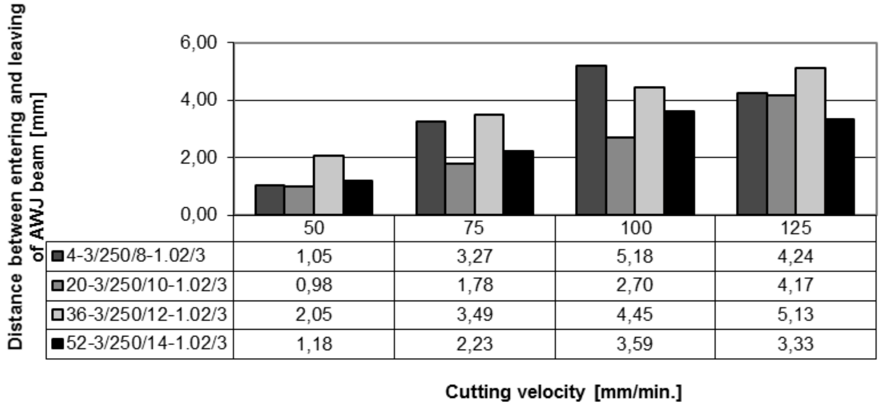
As shown in graph (**Fig. 5**), using a constant abrasive amount of 200 g.min^{-1} shows that distance between water jet entering and leaving is the most suitable choice at speed of feed at 50 mm.min^{-1}, and cutting speed of 125 mm.min^{-1} is the most inappropriate due to, that corrugated bottom cutting edge is the most visible.

As shown in graph (**Fig. 6**), using a constant abrasive amount of 250 g.min^{-1} shows that increasing of cutting speed depends on high visibility of corrugated bottom cutting edge. The distance between water jet entering and leaving is the most suitable choice at speed of feed at 50 mm.min^{-1}, and speed of feed at 125 mm.min^{-1} is the most inappropriate due to, that corrugated bottom cutting edge is the most visible.

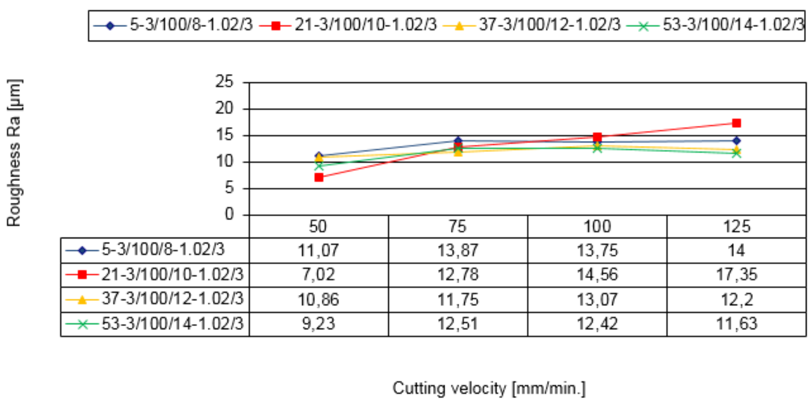


	50	75	100	125
4-3/250/8-1.02/3	1,05	3,27	5,18	4,24
20-3/250/10-1.02/3	0,98	1,78	2,70	4,17
36-3/250/12-1.02/3	2,05	3,49	4,45	5,13
52-3/250/14-1.02/3	1,18	2,23	3,59	3,33

Fig. 6 Evaluation of corrugated bottom cutting edge with abrasive amount of 250g.min^{-1}

3.2 Evaluation of the cutting edge roughness

Roughness measuring was realized by Mitutoyo SJ-301 roughness measurement [16, 18]. Middle value was evaluated for *Ra* roughness for each side of evaluated specimens. Roughness was evaluated resulting:



	50	75	100	125
5-3/100/8-1.02/3	11,07	13,87	13,75	14
21-3/100/10-1.02/3	7,02	12,78	14,56	17,35
37-3/100/12-1.02/3	10,86	11,75	13,07	12,2
53-3/100/14-1.02/3	9,23	12,51	12,42	11,63

Fig. 7 Dependence on the amount of abrasive roughness at constant average abr. ø1.02 mm nozzle, distance of nozzle material 5 mm, abrasive quantity of 100 g.min^{-1}

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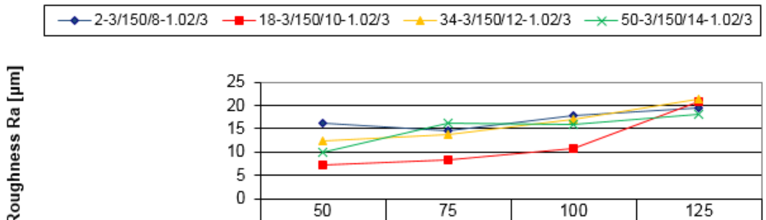
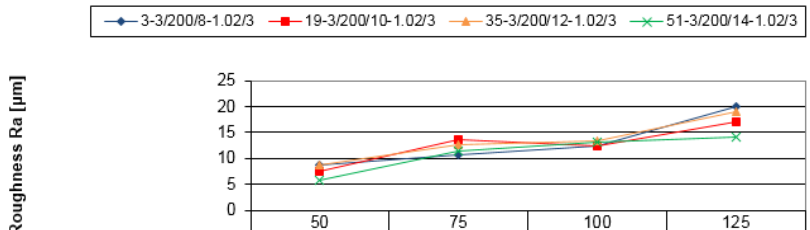


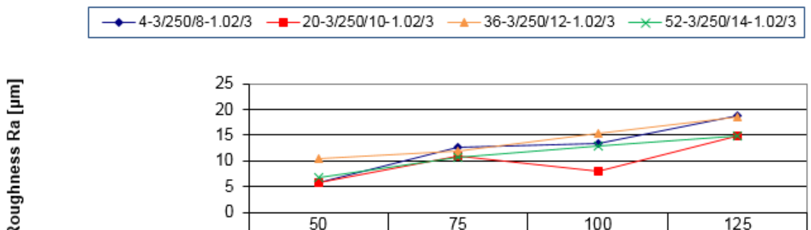
	50	75	100	125
2-3/150/8-1.02/3	16,16	14,52	17,71	19,46
18-3/150/10-1.02/3	7,18	8,35	10,64	20,8
34-3/150/12-1.02/3	12,39	13,79	17,01	21,21
50-3/150/14-1.02/3	10,05	16,04	15,89	18,2

Fig. 8 Dependence on the amount of abrasive roughness at constant average abr. ø1.02 mm nozzle, distance of nozzle material 3 mm, abrasive quantity of 150 $g.min^{-1}$



	50	75	100	125
3-3/200/8-1.02/3	8,61	10,71	12,35	20,05
19-3/200/10-1.02/3	7,37	13,57	12,5	17,01
35-3/200/12-1.02/3	8,82	12,73	13,44	19,01
51-3/200/14-1.02/3	5,69	11,4	13,2	14

Fig. 9 Dependence on the amount of abrasive roughness at constant average abr. ø1.02 mm nozzle, distance of nozzle material 3 mm, abrasive quantity of 200 $g.min^{-1}$



	50	75	100	125
4-3/250/8-1.02/3	5,82	12,71	13,33	18,65
20-3/250/10-1.02/3	5,65	10,82	7,96	14,92
36-3/250/12-1.02/3	10,47	11,86	15,42	18,5
52-3/250/14-1.02/3	6,69	10,74	12,75	14,85

Fig. 10 Dependence on the amount of abrasive roughness at constant average abr. ø1.02 mm nozzle, distance of nozzle material 3 mm, abrasive quantity of 250 $g.min^{-1}$

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Based on the assessment results, it was found that the positive effect on the quality of the cutting edge has lower speed of feed and more of abrasive. At a speed of feed at 50 $mm.min^{-1}$ abrasives and weights of 200 $g.min^{-1}$, the roughness ranged from 5.69 to 8.82 micron, which appeared to be optimal ratio selected. Negative impact on the quality of the cutting edge is a speed of feed, 100 $mm.min^{-1}$ and 125 $mm.min^{-1}$ surface roughness at a cutting speed of feed at 125 $g.min^{-1}$ abrasives and weights 150 g.min-1 ranged between 18.2 to 21.21 microns.

3.3 Evaluation of the total cutting depth

Cutting depth is affected not only by mechanic qualities of materials, their hardness and toughness but also kind of abrasive used and hardness [13, 14]. Crossing a certain ratio of hardness between materials treated and abrasive strongly reduces the amount of material. For the purpose of measuring cutting depth, i.e. longest jet beam, the PowerFix slide ruler was used. Specimens were evaluated optically; distance was measured by means of the ruler. The values measured were entered in tables on the basis of which graphic evaluations were made. **Table 2** results, that constant quantity of abrasive 100 $g.min^{-1}$ and lowest speed of feed at 50 $mm.min^{-1}$ was able to achieve the complete passage of the beam through the material; resp. total cutting depths were the longest. On the other hand, with increasing of speed of feed there was a lack of penetration of the beam into the material, resulting into incomplete severing of the material, resp. it was the smallest length of the beam. Speed of feed at 125 $mm.min^{-1}$ clearly shows the worst divided material, the smallest cutting depths.

Table 2 Measured beam length - 100 $g.min^{-1}$ of abrasive amount.

Specimen no.	**Speed of feed [$mm.min^{-1}$]**			
	50	75	100	125
5-3/100/8-1.02/5	15	10.31	7.94	6.43
21-3/100/10-1.02/5	15	12.97	10.70	6.80
37-3/100/12-1.02/5	15	13.24	7.85	7.48
53-3/100/14-1.02/5	15	11.37	8.51	-

Table 3 results, that constant quantity of abrasive 150 $g.min^{-1}$ and the speed of feed at 50 $mm.min^{-1}$ and 75 $mm.min^{-1}$ seem to be the most optimal choice, because using this velocities, the material was totally divided in the longest total cutting depth. On the other hand, with increasing of cutting velocities to 125 $mm.min^{-1}$ there was a lack of penetration of the beam into only one side of specimen and other sides was not so enough divided and it resulting into the worst divided material, the smallest cutting depths.

Table 3 Measured beam length - 150 $g.min^{-1}$ of abrasive amount.

Specimen no.	**Cutting velocities [$mm.min^{-1}$]**			
	50	75	100	125
2-3/150/8-1.02/3	15	15	11.66	8.39
18-3/150/10-1.02/3	15	15	15	10.55
34-3/150/12-1.02/3	15	15	13.30	9.35
50-3/150/14-1.02/3	15	15	13.15	15

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Table 4 results, that constant quantity of abrasive 200 g.min^{-1} and the cutting velocities of 50 mm.min^{-1} and 75 mm.min^{-1}, the material was totally divided in the longest total cutting depth and it using this amount of abrasive seems to be a good choice. The cutting velocities to 125 mm.min^{-1} seems that there was a lack of penetration of the beam into the specimen and no one specimen was divided totally and it result the smallest cutting depths, which was non-compliant.

Table 4 Measured beam length - 200 g.min^{-1} of abrasive amount.

Specimen no.	**Cutting velocities [mm.min^{-1}]**			
	50	75	100	125
3-3/200/8-1.02/3	15	15	14.11	12.68
19-3/200/10-1.02/3	15	15	15	12.71
35-3/200/12-1.02/3	15	15	15	12.01
51-3/200/14-1.02/3	15	15	15	11.25

Table 5 results, that constant quantity of abrasive 250 g.min^{-1} highly impact the penetration of the jet into the material. Speed of feed to 50 mm.min^{-1} and 75 mm.min^{-1} seems to be the most optimal and the speed of feed at 125 mm.min^{-1} is non-compliant.

Table 5 Measured beam length - 250 g.min^{-1} of abrasive amount.

Specimen no.	**Speed of feed [mm.min^{-1}]**			
	50	75	100	125
4-3/250/8-1.02/3	15	15	13.61	11.74
20-3/250/10-1.02/3	15	15	15	15
36-3/250/12-1.02/3	15	15	15	12.27
52-3/250/14-1.02/3	15	15	15	12.02

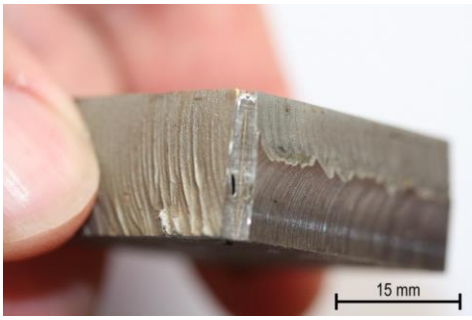

Fig. 17 Specimen no.5.3 – left side cut by 50m.min^{-1}, right side cut by 125 mm.min^{-1} at 150g.min^{-1} amount of abrasive

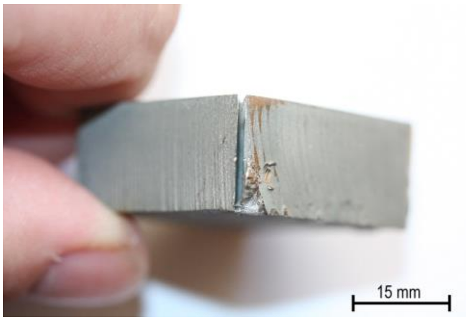

Fig. 18 Specimen no.20.3 - left side cut by 50 mm.min^{-1}, right side cut by 125 mm.min^{-1} at 250 g.min^{-1} amount of abrasive.

Based on the evaluation results, it was found that the advantages of the longest length of the beam, resp. the greatest depth of beam penetration, is much lower speed of feed and greater weight of abrasives, which at its peak allows cutting even at top speed of feed. When a weight of 200 and 250 g.min^{-1}, it was possible to experience a substantial differences in length of the beam

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from the value at lower weights. The negative effect on the depth of beam penetration was a higher speed of feed and low weight of abrasive. Only one specimen (20-3/250/10-1.02/3) was at all cutting velocities totally divided and it was when using a constant amount of abrasive 250 $g.min^{-1}$. The way how affects the speed of feed and the amount of abrasives to beam penetration, shows (**Fig. 17**) and (**Fig. 18**).

Conclusions

In this article, the abrasive water jet cutting process was reviewed and verified by experimental area of influence of selected specimen parameters on the final quality of surface. This will allow, for any necessary further research, to optimize the technological advances in production technology in components abrasive water jet cutting. As the assessment results, it has been determined that the distance between water jet entering and water jet leaving is decreased with the increasing abrasive amount and by following lower cutting rates. The increasing of a cutting rate negatively effects the quality of the cut surface and the size of the distance between water jet entering and water jet leaving, because the increasing of a cutting rate increases also values of the mentioned parameters. As to the distance between water jet entering and water leaving, as an acceptable corrugated bottom cutting edge is considered the one visible by the naked eye because the bottom edge of the cut surface is no more relatively straight then. It was found that the positive effect on the quality of the cutting edge has lower speed of feed and more of abrasive. Based on the evaluation results, it was found that the advantages of the longest length of the beam, resp. the greatest depth of beam penetration, is much lower speed of feed and greater weight of abrasives, which at its peak allows cutting even at top speed of feed.

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