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Some Analyze Considerations of the Kerf Variation for Abrasive Water Jet Cutting of a Steel Material

PhD. Stud. Eng. **Paul A. BASARMAN**[1]**,** PhD. Stud. Eng. **Bogdan CIORUŢA**[1]

[1]Technical University of Cluj-Napoca – North University Center at Baia Mare, Faculty of Engineering, Victor Babeş str., No. 62A, 430083, Baia Mare, Romania
adrian.basarman@cunbm.utcluj.ro / bciorutza@yahoo.com

Abstract: *A modern method of cutting materials is considered to be the abrasive water jet (AWJ) cutting method. It is a method that is in full ascension nowadays regarding, especially, the level of usability in production. In order to have the adequate setup for abrasive water jet cutting on a certain system, the surface quality, the kerf aspect, the shape and respectively the form of the obtained part have to be carefully analysed. This paper presents the results obtained after cutting a square shaped part, made of S355 material. In the present study, there were analysed both the inside and the outside of the cut, the kerf width, the aspect of the taper and the profile deviation, in accordance with a computer numerical control (CNC) attached to the cutting machine used.*

Keywords: *abrasive water jet (AWJ), surface quality, 3D measuring of surface, kerf variation.*

1. Introduction

The abrasive water jet (AWJ) cutting method is as mentioned in the abstract a modern method for cutting different types of materials. There is no relevant literature that specifies a formula for calculation of the stock left for machining of metallic parts. In this case, the first thing that had to be studied was the surface aspect of the steel parts after cutting and measuring the kerf size and the profile deviations, both operations being carried out in relation to and as adaptation to other similar research. In the process of cutting the materials using abrasive water jet (AWJ), the surface resulted can be very rough or very fine, the main difference between them would be the combination of the next variables: *thickness of the steel part*, *hardness of the material*, *water pressure used for cutting*, *type and quality of the abrasive particles* and *the cutting speed* [8].
By reference to the scientific literature consulted, Valíček et al. [7] divided the resulted surface, after cutting it with abrasive water jet (AWJ), based upon *the surface roughness*, in three different sectors: *primary impact zone, smooth zone* and *rough zone*. Regarding the way of calculating the cutting feed rate, other researchers interested in the same issues proposed a mathematical modell that had a big number of parameters as independent variables [4]. Researches in this field have been made by authors like Fowler [1], Popan et al. [5], for the purpose of milling the surface of metal parts using this technology. Hlaváček et al. [2], Hloch et al. [3] and Valíček et al. [6] investigated the way of turning materials using abrasive water jet (AWJ) cutting method.

2. Work method and experimental setup

The experiments were conducted using an abrasive water jet (AWJ) cutting machine - *Bystronic ByJet Pro L* - presented in Figure 1a. The advantage in using this kind of method is that the cutting element is the abrasive water jet (AWJ) - distinct in relation to the conventional cutting methods used in production, where there is a contact of the solid tool with parts that need to be cut. Another important advantage to be mentioned of this method is that during the cutting process, the materiall is cooled down just by the water, acting like a coolant liquid.
The abrasive water jet (AW) cutting machine has several components which are presented, in detailed, in Figure 1b.
The main components of the abrasive water jet (AWJ) machine are the followings: 1) catch tank; 2) workpiece; 3) cutting head; 4) abrasive delivery system; 5) work motions system; 6) grill for supporting the parts. This abrasive water jet (AWJ) cutting machine is a computer controlled machine (CCM), assisted easily only by an operator.

Fig. 1. a) The Bystronic ByJet Pro L machine; **b)** Elements of the considered abrasive water jet machine

In order to take notice of how the surface has modified after cutting, we had to analyse, in parallel, both the interior and the exterior of the kerf, as presented in Figure 2a and also, in that way, by measuring the kerf width, we can experimentally determine the stock left for machining, needed in order to have a correct and more accurate cut.

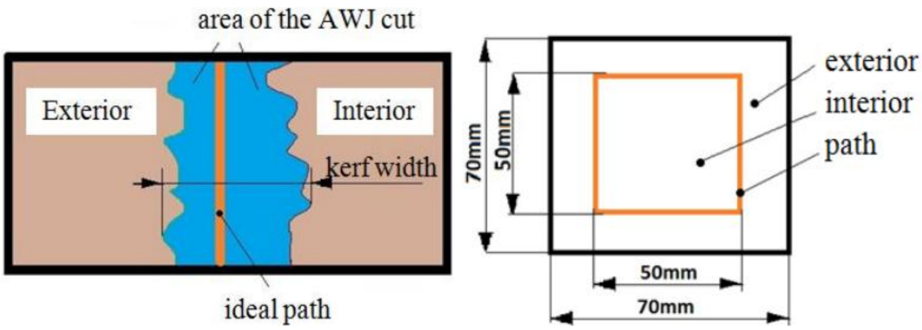

Fig. 2. a) General aspect of the abrasive water jet cut; **b)** Design for cutting

These experiments were conducted on a S355 material plate, of 30 mm thickness. The design on how the cut was made is presented above, in Figure 2b. From the list of cutting conditions offered by the machine manufacturer, there were selected the slowest, that can possibly offer the best results regarding the quality of the cut. The selected parameters are presented in Table 1.

Table 1: The parameters used for the cutting regime

Parameters	Value selected
Breakthrough time	19 s
Breakthrough pressure	3600 bar
Abrasive material used	GMA Garnet 80 Mesh (150-300 micron)
Quantity of abrasive material	342 g/min
Cutting pressure	3600 bar
Cutting speed	27 mm/min
Interior diameter of sapphire nozzle	0.28 mm
Exterior diameter of nozzle	0.8 mm

We considered that the first step in conducting the experiments is putting the steel part (S355) on the machine's grill support (6 – from Figure1b) and fixing it down, using the machine clamping system. After this step, the program of cut is loaded in the software of the machine, the next step including the selection of the cutting conditions. Subsequently, the part is cut.
The part that has been cut is presented right after cutting, in Figure 3a, still on the machine, and after taking out of the base plate, in Figure 3b.

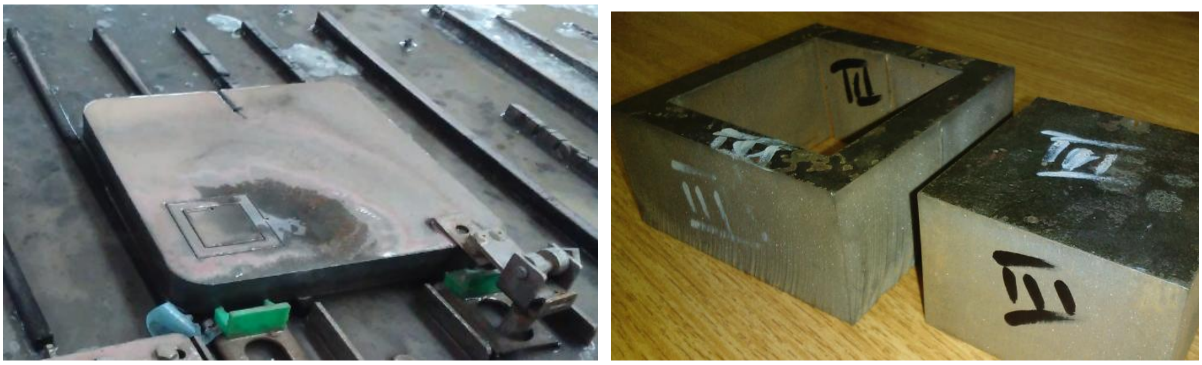

Fig. 3. a) Part after cutting still on the machine; **b)** Same part after taking out of the base plate

After cutting the steel part, for both parts resulted, as in Figure 3b, in order to determine the exact aspects all the surfaces, we focus on splitting the surface in three rows. Further, using a 3D measuring arm, as presented in Figure 4a, there were taken a number of 10 measurements on each row, having a total of 30 points measured on a surface, as presented in the Figure 4b.

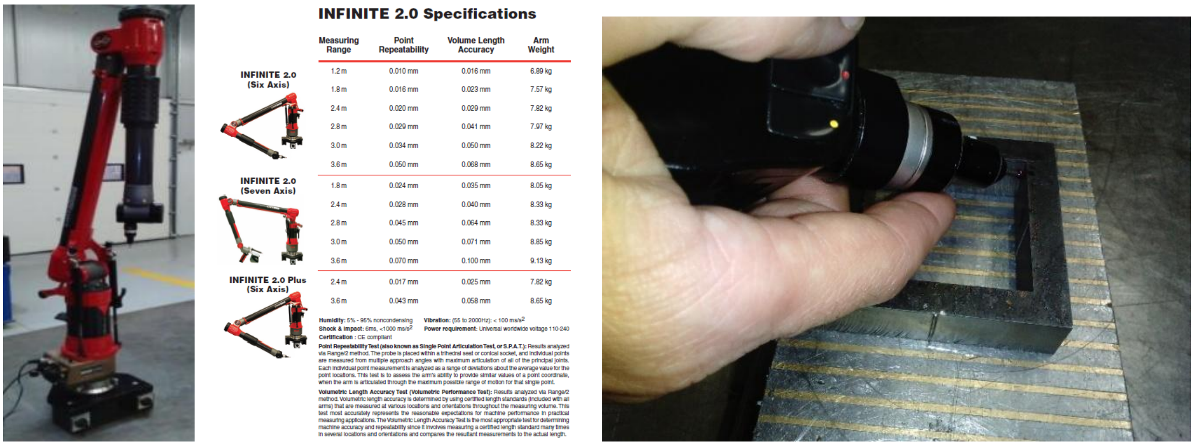

Fig. 4. a) Cimcore Infinite 3D measuring arm, v.2.0; **b)** The surfaces analysed after cutting operation

The rows were measured separated and analysed one with each other, both for the interior and for the exterior of the cut. Being a square part, that meant having four exterior surfaces (E1-4) and four interior surfaces (I1-4), they were analysed together (e.g. E1 with I1), as in the Figure 5a. As previously specified, for every surface measured independently we obtain a set of values, as in Figure 5b.

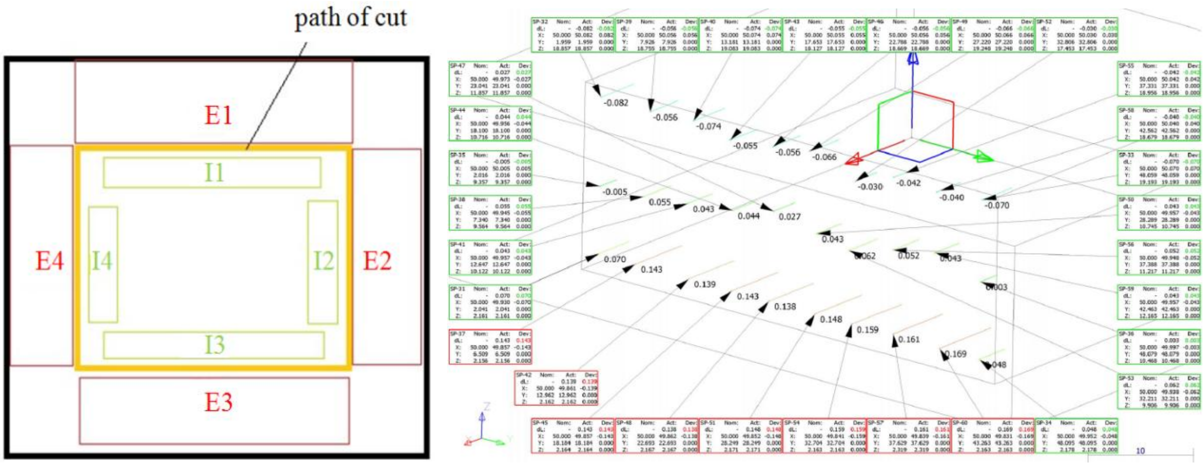

Fig. 5. a) The way of measuring the points; **b)** The measuring set values obtained for the cutting part

After measuring every surface, the values were included in Table 2.

Table 2: Values measured on every surface on the steel part cut using abrasive water jet (AWJ) method

Surface I	Interior	1	2	3	4	5	6	7	8	9	10
	Ideal surface	0	0	0	0	0	0	0	0	0	0
	up	0.910	0.879	0.872	0.870	0.923	0.922	0.900	0.910	0.900	0.920
	middle	0.787	0.746	0.747	0.750	0.854	0.812	0.765	0.764	0.759	0.789
	down	0.632	0.576	0.563	0.603	0.688	0.645	0.587	0.566	0.608	0.644
	Exterior	1	2	3	4	5	6	7	8	9	10
	up	-0.097	-0.083	-0.080	-0.084	-0.120	-0.069	-0.058	-0.056	-0.058	-0.078
	middle	-0.286	-0.217	-0.239	-0.213	-0.398	-0.292	-0.204	-0.177	-0.182	-0.301
	down	-0.399	-0.325	-0.334	-0.358	-0.524	-0.450	-0.310	-0.297	-0.328	-0.486
Surface II	Interior	1	2	3	4	5	6	7	8	9	10
	Ideal surface	0	0	0	0	0	0	0	0	0	0
	up	0.939	0.909	0.907	0.894	0.903	0.904	0.908	0.909	0.906	0.937
	middle	1.161	1.072	1.075	1.076	1.074	1.072	1.078	1.067	1.079	1.161
	down	1.264	1.225	1.190	1.199	1.199	1.174	1.191	1.196	1.214	1.268
	Exterior	1	2	3	4	5	6	7	8	9	10
	up	-0.067	-0.050	-0.061	-0.058	-0.059	-0.054	-0.057	-0.048	-0.058	-0.071
	middle	0.022	0.110	0.100	0.115	0.110	0.096	0.142	0.114	0.099	0.035
	down	0.165	0.285	0.295	0.299	0.290	0.288	0.289	0.282	0.259	0.213
Surface III	Interior	1	2	3	4	5	6	7	8	9	10
	Ideal surface	0	0	0	0	0	0	0	0	0	0
	up	0.856	0.844	0.850	0.860	0.881	0.882	0.872	0.889	0.889	0.924
	middle	0.799	0.739	0.718	0.724	0.730	0.749	0.759	0.766	0.763	0.829
	down	0.685	0.565	0.546	0.583	0.553	0.570	0.568	0.597	0.590	0.706
	Exterior	1	2	3	4	5	6	7	8	9	10
	up	-0.136	-0.100	-0.099	-0.095	-0.089	-0.089	-0.091	-0.092	-0.101	-0.122
	middle	-0.300	-0.190	-0.192	-0.202	-0.208	-0.205	-0.197	-0.202	-0.193	-0.261
	down	-0.443	-0.326	-0.332	-0.329	-0.309	-0.329	-0.314	-0.328	-0.327	-0.379
Surface IV	Interior	1	2	3	4	5	6	7	8	9	10
	Ideal surface	0	0	0	0	0	0	0	0	0	0
	up	0.965	0.936	0.930	0.914	0.906	0.897	0.899	0.887	0.880	0.885
	middle	1.139	1.051	1.036	1.015	1.006	0.979	0.998	0.976	0.989	1.062
	down	1.211	1.105	1.098	1.072	1.098	1.075	1.054	1.055	1.056	1.140
	Exterior	1	2	3	4	5	6	7	8	9	10
	up	-0.030	-0.026	-0.021	-0.028	-0.036	-0.048	-0.038	-0.058	-0.060	-0.099
	middle	0.007	0.056	0.078	0.051	0.052	0.035	0.046	0.027	0.019	-0.057
	down	0.127	0.193	0.181	0.147	0.174	0.158	0.139	0.143	0.149	-0.007

3. Analysing the results

After measuring every surface, as mentioned before, the values were presented both referring to the ideal path of cut and on each side of the path. In some cases, as presented in Table 2, some of the resulted values were considered as negative. These being stated, regarding the kerf width, the values from each side of the ideal path were summed together, thereby hoping to form the resulted measurement of the kerf width, as presented in the Table 3.

Table 3: The value of the kerf width on every surface

Surface I	No. of meas.	1	2	3	4	5	6	7	8	9	10
	up	1.007	0.962	0.952	0.954	1.043	0.991	0.958	0.966	0.958	0.998
	middle	1.073	0.963	0.986	0.963	1.252	1.104	0.969	0.941	0.941	1.090
	down	1.031	0.901	0.897	0.961	1.212	1.095	0.897	0.863	0.936	1.130
Surface II	No. of meas.	1	2	3	4	5	6	7	8	9	10
	up	1.006	0.959	0.968	0.952	0.962	0.958	0.965	0.957	0.964	1.008
	middle	1.139	0.962	0.975	0.961	0.964	0.976	0.936	0.953	0.980	1.126
	down	1.099	0.940	0.895	0.900	0.909	0.886	0.902	0.914	0.955	1.055
Surface III	No. of meas.	1	2	3	4	5	6	7	8	9	10
	up	0.992	0.944	0.949	0.955	0.970	0.971	0.963	0.981	0.990	1.046
	middle	1.099	0.929	0.910	0.926	0.938	0.954	0.956	0.968	0.956	1.090
	down	1.128	0.891	0.878	0.912	0.862	0.899	0.882	0.925	0.917	1.085
Surface IV	No. of meas.	1	2	3	4	5	6	7	8	9	10
	up	0.995	0.962	0.951	0.942	0.942	0.945	0.937	0.945	0.940	0.984
	middle	1.132	0.995	0.958	0.964	0.954	0.944	0.952	0.949	0.970	1.119
	down	1.084	0.912	0.917	0.925	0.924	0.917	0.915	0.912	0.907	1.147

4. Analysing the aspect of surface

The values presented in Table 3 are correspondent directly proportional with the kerf width. We can observe that the *smallest kerf width* from all the surfaces analysed is *0.862 mm* (surface III) and the *biggest kerf width* is *1.252 mm* (surface I).
Because the part was cut with the same cutting parameters, on every surface, the values should be approximately the same; thus, we will present only two cases: first one, when the cutting head moved longitudinally and second one, when the cutting head moved transversally. We will take the first two surfaces for analysing, by analogy being able to debate the other remaining surfaces.

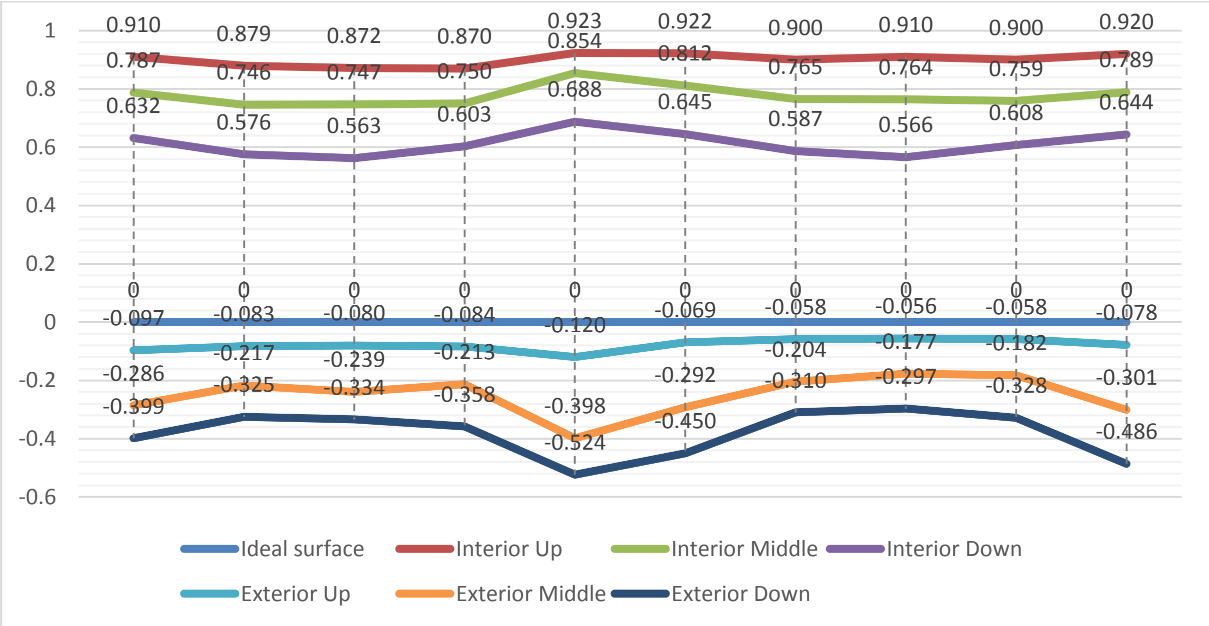

Fig. 6. Top view for the aspect of the surface I

In Figure 6, it can be seen the aspect of the cut, and also of the surfaces, both for the interior of the cut and also for the exterior. One can see that the surface is not straight, presents a V shape taper, which slides in a certain direction, towards the interior and the lines have an irregular aspect. Putting the values together, it was generated the aspect of the width of cut, shown in the Figure 7.

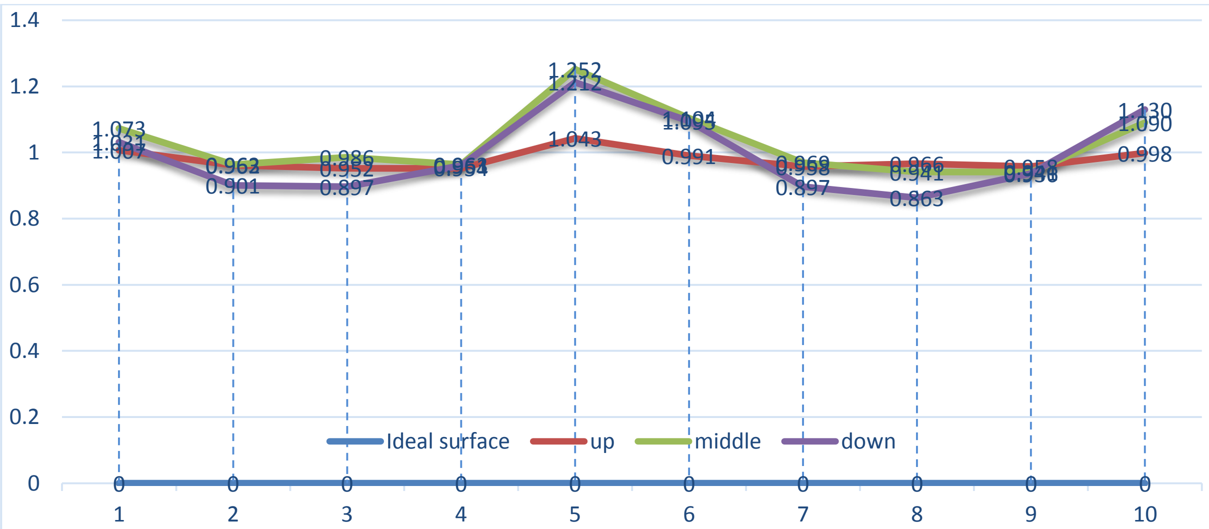

Fig. 7. The width of cut for surface I

As it can be observed in Figure 7, the bulging aspect of the surface is accentuated in the middle, between point 4 and point 7, and even more up in the corners, from point 9 to 10. That may result because of the machine error while switching the movement direction from one axis to another.

Analysing the next surface, presented in Figure 8, different aspects can be seen.

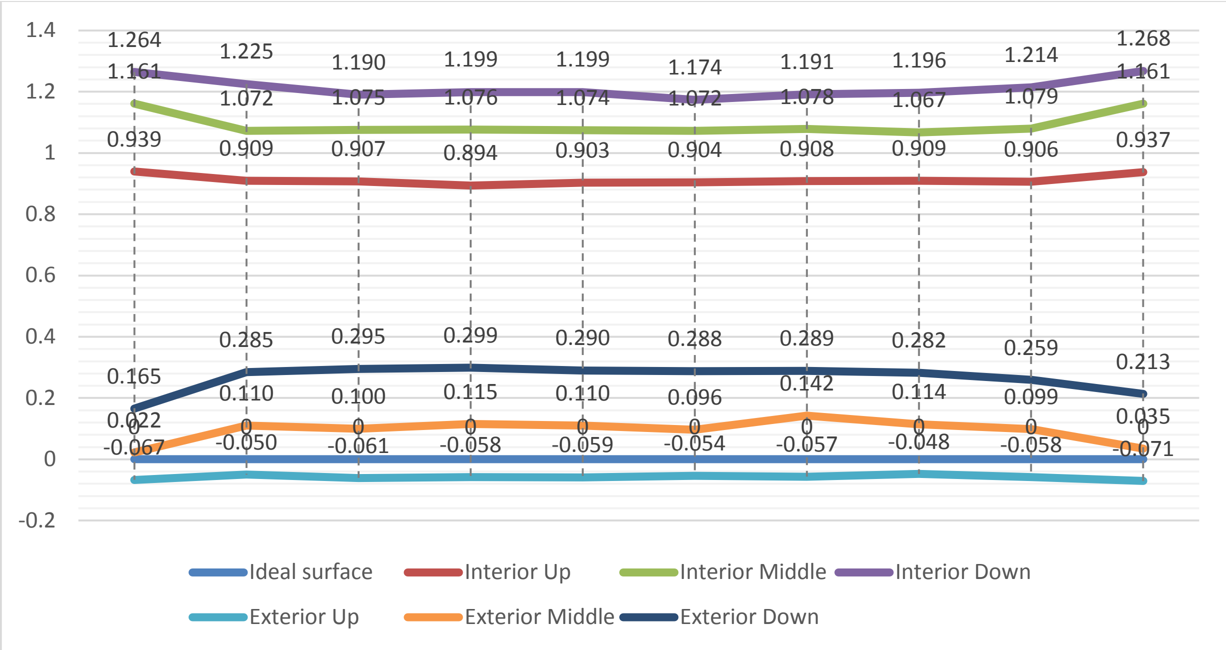

Fig. 8. Top view for the aspect of the surface II

In Figure 8, a major difference in relation to the surface I can be observed. The ideal surface is not incorporated in the exterior surface anymore. The surface presents a small V shaped taper, but in this case, the sliding is towards the exterior.

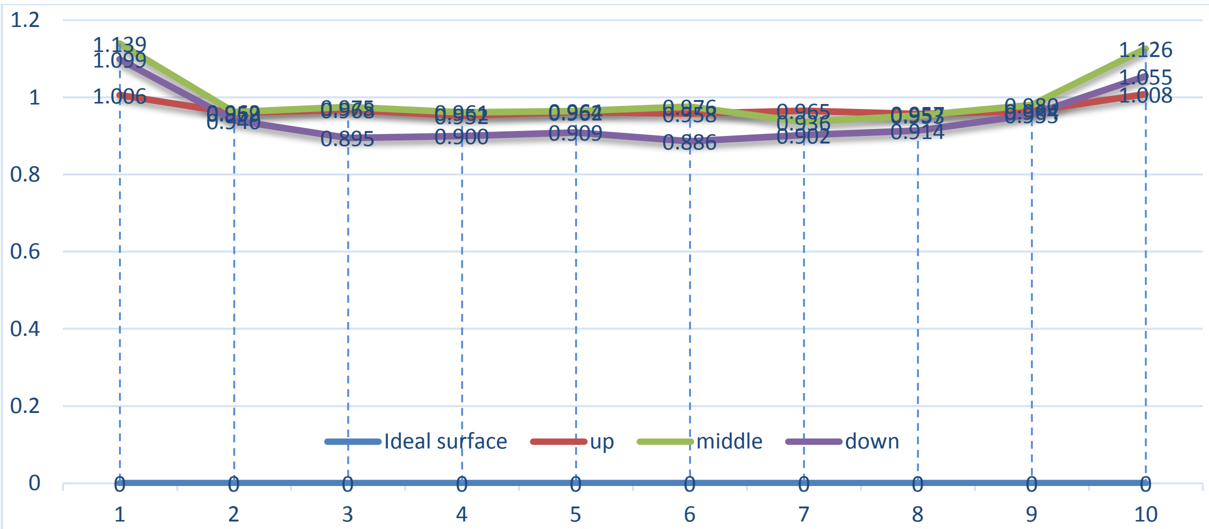

Fig. 9. The width of cut for surface II

As it can be observed in Figure 9, the surface has not the same bulging aspect in the middle, as in the Figure 7, the measured values outlining with great smoothness a surface that has a regular shape, compared to the width of cut for surface I.

5. Conclusions and future research directions

After analysing all the results of the described experiments, realised for a part cutted from a specified material (S355), the following conclusions can be highlighted:

a) The surface aspect has a slight deviation of profile, because of the error of the machine. The *smallest kerf width* vs. the *biggest kerf width* resulted is *0.863...1.252 mm* (surface I), *0.886...1.139 mm* (surface II), *0.862...1.128 mm* (surface III) and *0.907...1.147 mm* (surface IV). This confirms that the error of the machine is the one causing this, while it's switching the movement direction from one axis to another, but taking a look at the values of the kerf width on both surfaces analysed, the difference between the values isn't very high. In order to verify this hypothesis, more experiments are required, for different cutting conditions.

b) The maximum stock needed to be left for machining with abrasive water jet (AWJ) is *1.252 mm* for a *30 mm* thickness steel S355 part.

c) The aspect of the surface after cutting it with abrasive water jet (AWJ) has a bulging in the middle (surface I) and it is slightly pointier in the corners (surface II).

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