ANALYSE OF THE KERF VARIATION FOR ABRASIVE WATER JET (AWJ) CUTTING OF STEEL

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ABSTRACT: A modern method of cutting materials is the abrasive water jet cutting method. It is a method that is in full ascension regarding the level of usability in production. In order to have the adequate setup for 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 analysed. This paper presents the results obtained after cutting one square shaped part, made of 1C45 material. In the 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.
KEYWORDS: abrasive water jet, surface aspect, surface quality, 3D measuring of surface, kerf, taper

1. INTRODUCTION

The water jet cutting method is a modern method for cutting 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.

In the process of cutting the materials using abrasive water jet, the surface resulted can be very rough or very fine, the 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;
- mixture between the water and the abrasive material;
- type and quality of the abrasive particles;
- cutting speed.

Valíček et al. [7] divided the resulted surface, after cutting it with abrasive water jet, based upon the surface roughness, in three sectors:

1) Primary impact zone;
2) Smooth zone;
3) Rough zone.

Regarding the way of calculating the cutting feed rate, the researcher Zeng proposed a mathematical model that had a big number of parameters as independent variables [4].

Researches in this field, regarding the water jet, 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. Hloch et al. [3], Hlaváček et al. [2] and Valíček et al. [6] investigated the way of turning materials using abrasive water jet cutting method.

2. EXPERIMENTAL SETUP

2.1 The abrasive water jet (AWJ) cutting machine

The experiments were conducted using an abrasive water jet (AWJ) cutting machine - Bystronic ByJet Pro L - presented in Figure 1.

Figure 1. Bystronic ByJet Pro L

The advantage in using this method is that the cutting element is the abrasive water jet (AWJ); the method is distinct in relation to the conventional cutting methods, where there is a contact of the solid tool with parts that need to be cut.

Another advantage of this method is that during the cutting process, the material is cooled down just by the water, acting like a coolant liquid.

The abrasive water jet (AWJ) cutting machine has several components which are presented in Figure 2.

Figure 2. Elements of the abrasive water jet machine

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 (CNC).

2.2 Preparation for experiments

In order to take notice of how the surface has modified after cutting, we had to analyse both the interior and the exterior of the kerf, as presented in Figure 3 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.

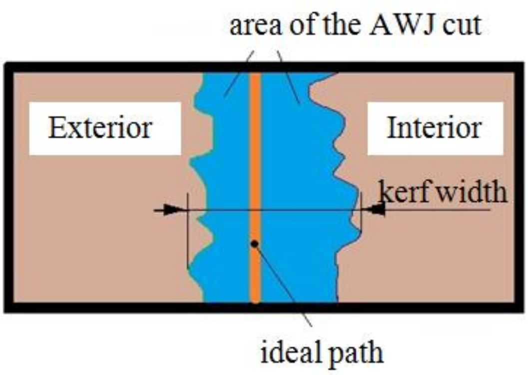


Figure 3. General aspect of the abrasive water jet cut

These experiments were conducted on a 1C45 material plate, of 20 mm thickness.

The design on how the cut was made is presented in Figure 4.

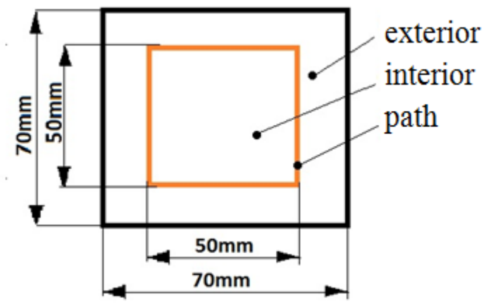


Figure 4. Design for cutting

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	13 s
Breakthrough pressure	3600 bar
Abrasive material used	GMA Garnet 80 Mesh (300-150 micron)
Quantity of abrasive material	342 g/min
Cutting pressure	3600 bar
Cutting speed	45 mm/min
Interior diameter of sapphire nozzle	0.28 mm
Exterior diameter of nozzle	0.8 mm

2.3 Conducting the experiments

The first step in conducting the experiments is putting the steel part on the machine's grill support and fixing it down, using the machine clamping system.

After this step, the program of cut is loaded in the software of the machine and the next step is selecting the conditions of cutting, as they are presented in Table 1. Subsequently, the part is cut. The part that has been cut is presented right after cutting, still on the machine, in the Figure 5, and after taking out of the base plate, in Figure 6.

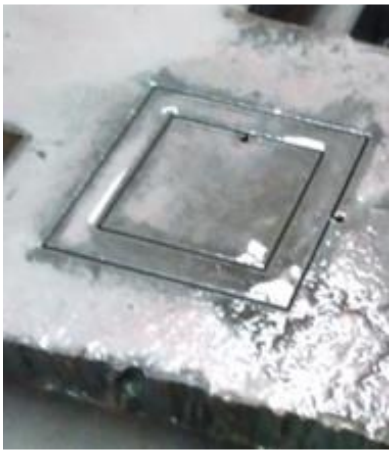


Figure 5. Part after cutting it with abrasive water jet (AWJ)

Figure 6. 1C45 steel part cut with abrasive water jet (AWJ)

2.4 Measuring the profile deviations of the part cut using abrasive water jet (AWJ)

After cutting the steel part, for both parts resulted, as one can observe in Figure 6, all the surfaces 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 (example - exterior E1 with interior I1), as shown in the Figure 7.

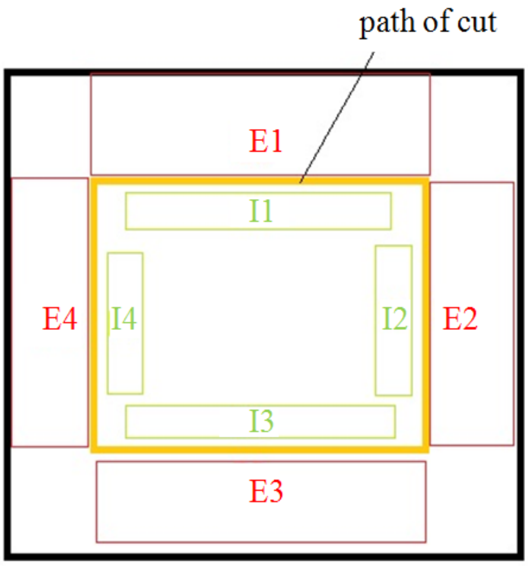


Figure 7. The surfaces analysed after cutting

In order to determine the exact aspects of the surfaces, the surface was divided in three rows and using a 3D measuring arm, as presented in Figure 8, 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 9.

Figure 8. Cimcore Infinite 2.0 3D measuring arm

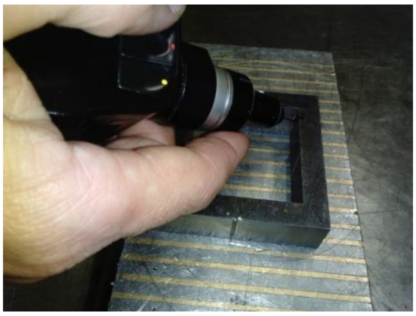


Figure 9. Measuring the exterior surface cut by abrasive water jet (AWJ)

As previously specified, every surface was measured independently and a set of values resulted for each surface, as presented in Figure 10. Those values were set to be measured from the ideal path of cut, specified in the Figures 4 and 7.

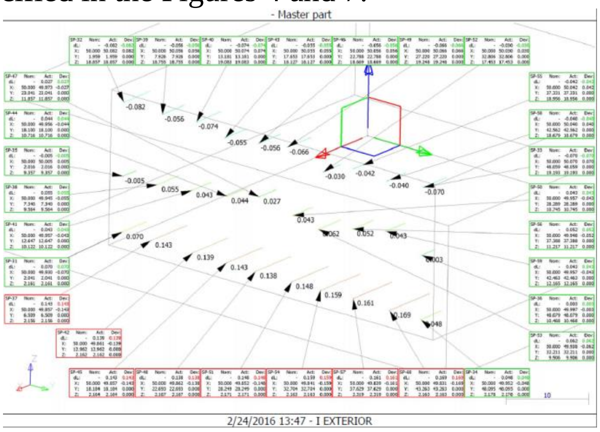


Figure 10. The way of measuring the points on the analysed surface

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)

Surface	*Location*	*Row*	*M 1*	*M 2*	*M 3*	*M 4*	*M 5*	*M 6*	*M 7*	*M 8*	*M 9*	*M 10*
I	Interior	Up	0.882	0.865	0.861	0.858	0.864	0.868	0.871	0.880	0.888	0.918
		Middle	0.938	0.866	0.863	0.861	0.862	0.875	0.873	0.887	0.886	0.946
		Down	0.961	0.881	0.883	0.887	0.877	0.898	0.902	0.894	0.903	0.985
	Exterior	Up	-0.082	-0.056	-0.074	-0.055	-0.056	-0.066	-0.030	-0.042	-0.040	-0.070
		Middle	-0.005	0.055	0.043	0.044	0.027	0.043	0.062	0.052	0.043	0.003
		Down	0.070	0.143	0.139	0.143	0.138	0.148	0.159	0.161	0.169	0.048
II	Interior	Up	0.896	0.875	0.862	0.877	0.860	0.865	0.869	0.870	0.867	0.883
		Middle	0.834	0.771	0.756	0.771	0.767	0.769	0.771	0.756	0.764	0.812
		Down	0.750	0.651	0.663	0.656	0.670	0.668	0.668	0.671	0.664	0.728
	Exterior	Up	-0.085	-0.078	-0.074	-0.070	-0.064	-0.064	-0.069	-0.058	-0.067	-0.106
		Middle	-0.117	-0.073	-0.067	-0.063	-0.058	-0.060	-0.053	-0.062	-0.058	-0.135
		Down	-0.184	-0.114	-0.113	-0.096	-0.108	-0.114	-0.111	-0.087	-0.125	-0.178
III	Interior	Up	0.928	0.914	0.912	0.898	0.895	0.889	0.898	0.898	0.889	0.890
		Middle	0.968	0.898	0.881	0.883	0.869	0.871	0.859	0.858	0.860	0.937
		Down	0.985	0.875	0.868	0.861	0.852	0.850	0.843	0.846	0.839	0.896
	Exterior	Up	-0.028	0.007	-0.021	-0.009	-0.003	-0.015	-0.020	-0.024	-0.016	-0.081
		Middle	0.015	0.066	0.056	0.071	0.056	0.053	0.044	0.045	0.035	-0.023
		Down	0.048	0.126	0.127	0.117	0.121	0.104	0.104	0.105	0.099	0.033
IV	Interior	Up	0.881	0.870	0.876	0.878	0.914	0.907	0.903	0.890	0.898	0.918
		Middle	0.835	0.804	0.821	0.811	0.926	0.859	0.838	0.841	0.837	0.878
		Down	0.800	0.757	0.750	0.784	0.875	0.803	0.756	0.775	0.781	0.845
	Exterior	Up	-0.058	-0.047	-0.032	-0.036	-0.057	-0.043	-0.013	-0.007	-0.008	-0.032
		Middle	-0.073	-0.006	0.015	-0.001	-0.105	-0.027	0.016	0.034	0.027	-0.047
		Down	-0.087	0.014	0.006	0.000	-0.103	-0.029	0.023	0.032	0.040	-0.082

3. ANALYSING THE RESULTS

After measuring every surface, 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 (with minus sign).

Regarding the kerf width, the values from each side of the ideal path were summed together, to form the resulted measurement of the kerf width and the values are presented in the Table 3.

The values presented in Table 3 are correspondent directly proportional with the kerf width.

After analysing the values, one can observe that the *smallest kerf width* from all the surfaces analysed is 0,733 mm and the *biggest kerf width* was 1.031 mm**.**

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

Surface	**Row**	**M 1**	**M 2**	**M 3**	**M 4**	**M 5**	**M 6**	**M 7**	**M 8**	**M 9**	**M 10**
I	Up	0.964	0.921	0.935	0.913	0.920	0.934	0.901	0.922	0.928	0.988
	Middle	0.943	0.811	0.820	0.817	0.835	0.832	0.811	0.835	0.843	0.943
	Down	0.891	0.738	0.744	0.744	0.739	0.750	0.743	0.733	0.734	0.937
II	Up	0.981	0.953	0.936	0.947	0.924	0.929	0.938	0.928	0.934	0.989
	Middle	0.951	0.844	0.823	0.834	0.825	0.829	0.824	0.818	0.822	0.947
	Down	0.934	0.765	0.776	0.752	0.778	0.782	0.779	0.758	0.789	0.906
III	Up	0.956	0.907	0.933	0.907	0.898	0.904	0.918	0.922	0.905	0.971
	Middle	0.953	0.832	0.825	0.812	0.813	0.818	0.815	0.813	0.825	0.960
	Down	0.937	0.749	0.741	0.744	0.731	0.746	0.739	0.741	0.740	0.863
IV	Up	0.939	0.917	0.908	0.914	0.971	0.950	0.916	0.897	0.906	0.950
	Middle	0.908	0.810	0.806	0.812	1.031	0.886	0.822	0.807	0.810	0.925
	Down	0.887	0.743	0.744	0.784	0.978	0.832	0.733	0.743	0.741	0.927

4. ANALYSING THE ASPECT OF SURFACE

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;

- *second one*, when the cutting head moved transversally.

In this case, regarding the order of cut presented in Figure 7, we will take surface 1 and 2 for analysing.

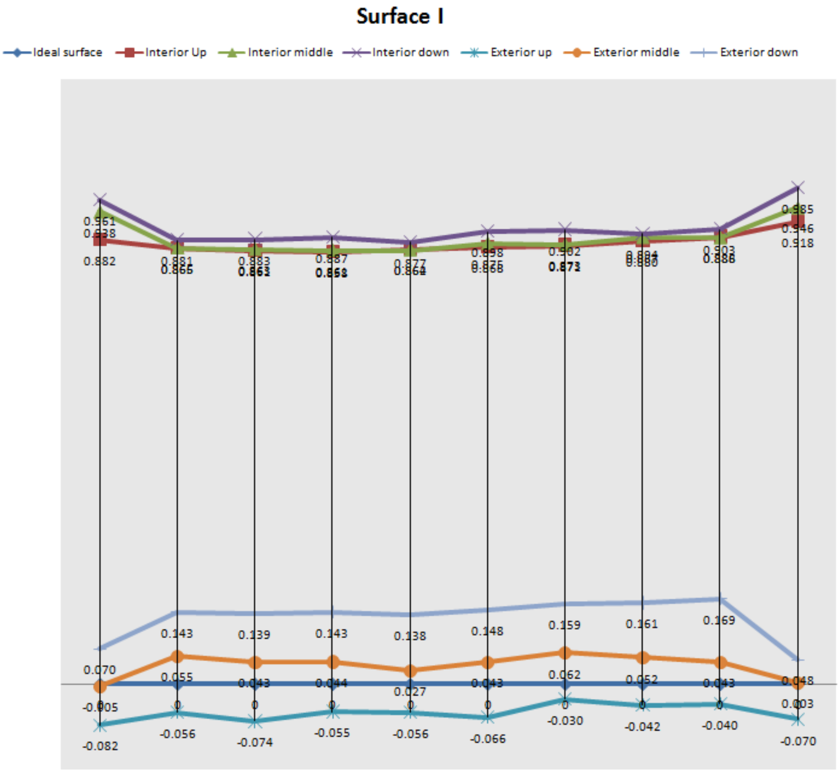
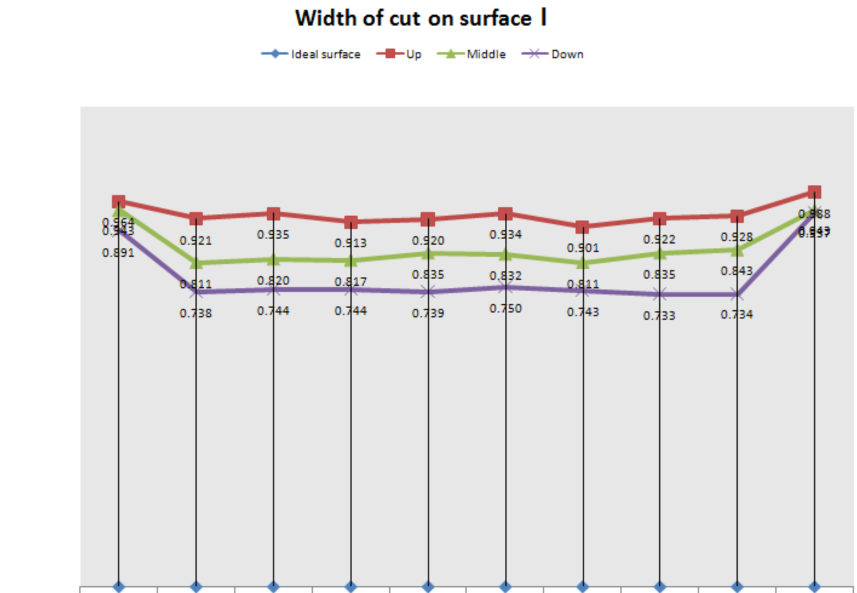


Figure 11. Top view for the aspect of the surface I

In Figure 11, 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 12.



	1	2	3	4	5	6	7	8	9	10
Ideal surface	0	0	0	0	0	0	0	0	0	0
Up	0.964	0.921	0.935	0.913	0.920	0.934	0.901	0.922	0.928	0.988
Middle	0.943	0.811	0.820	0.817	0.835	0.832	0.811	0.835	0.843	0.943
Down	0.891	0.738	0.744	0.744	0.739	0.750	0.743	0.733	0.734	0.937

Figure 12. The width of cut for surface I

As it can be observed in Figure 12, the bulging aspect of the surface is accentuated in the middle and even more up in the corners. That may result because of the machine error while switching the movement direction from one axis to another. The *smallest kerf width* resulted here is *0.733 mm* and the *biggest kerf width* is *0.988 mm.*

Analysing the next surface, presented in Figure 13, similar aspects can be seen, like the ones showed in Figure 11.

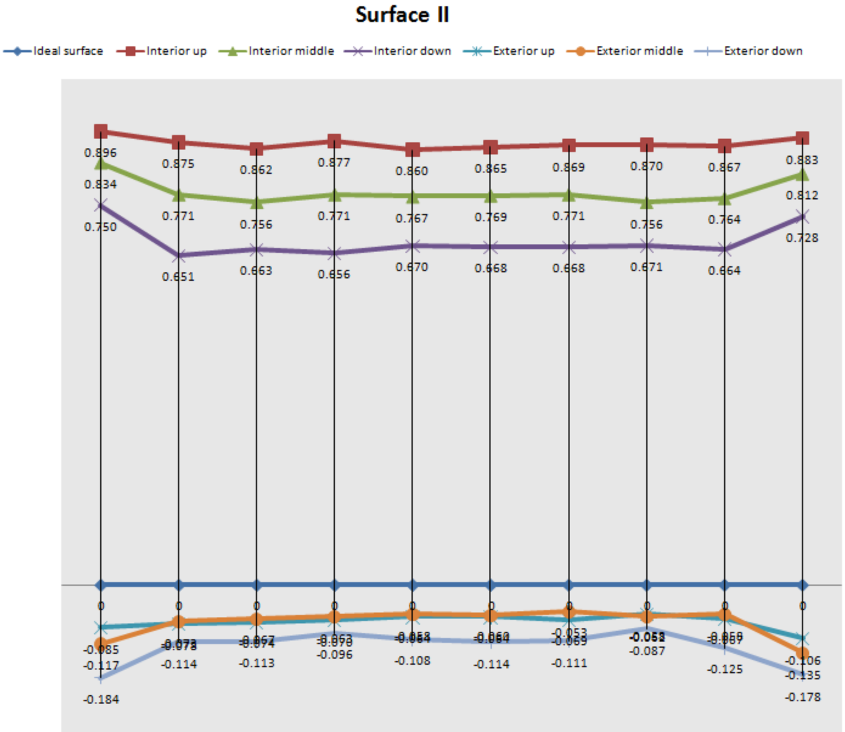
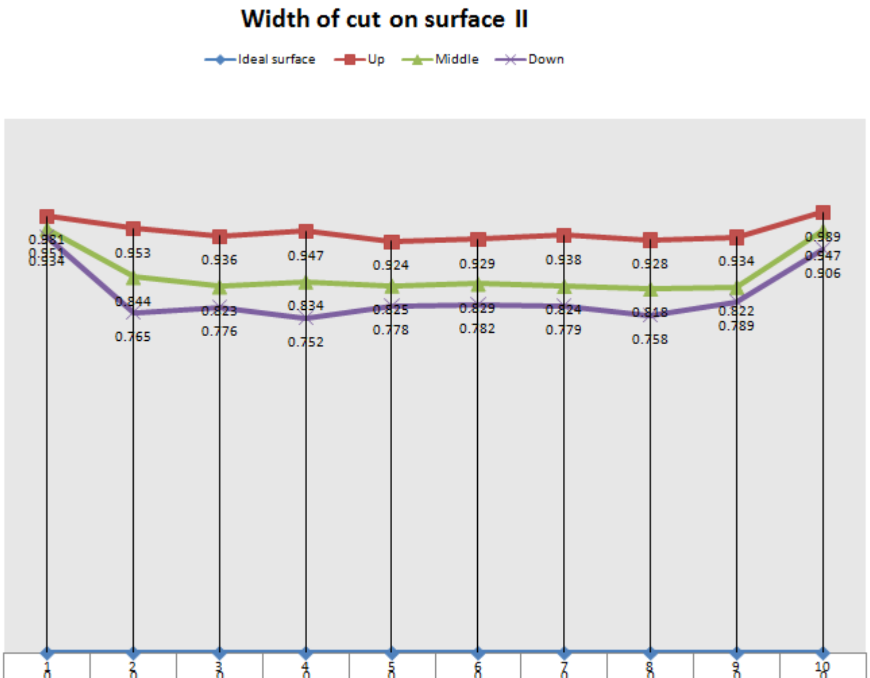


Figure 13. Top view for the aspect of the surface II

As one can see in Figure 13, it can be observed a little bit of difference in relation to the surface I. The ideal surface is not incorporated in the exterior surface anymore. The surface presents also a V shaped taper, but in this case, the sliding is towards the exterior. In Figure 14, one can observe the kerf width for the second surface.



	1	2	3	4	5	6	7	8	9	10
Ideal surface	0	0	0	0	0	0	0	0	0	0
Up	0.981	0.953	0.936	0.947	0.924	0.929	0.938	0.928	0.934	0.989
Middle	0.951	0.844	0.823	0.834	0.825	0.829	0.824	0.818	0.822	0.947
Down	0.934	0.765	0.776	0.752	0.778	0.782	0.779	0.758	0.789	0.906

Figure 14. The width of cut for surface II

As it can be observed in Figure 14, the surface has the same bulging aspect in the middle and more up in the corners, because the water jet kicked back, and also that the surface has the same irregular shape. The *smallest kerf width* resulted here is 0.752 mm and the *biggest kerf width* is 0.989 mm.

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 is not very high. In order to verify this hypothesis, more experiments are required, with different speeds and different thicknesses.

5. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

After analysing the results of the described experiments, the following conclusions can be highlighted:

1) The surface aspect has a slight deviation of profile, because of the error of the machine.

2) The maximum stock needed to be left for machining with abrasive water jet (AWJ) is *1.031 mm* for a *20 mm* thickness steel *1C45* part.

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

As directions of further research, the following can be considered:

1) Repeating the experiment for other materials or/and thicknesses;

2) Changing the cutting conditions and comparing the results;

3) Making a 3D version of the aspect of the surface out of all the points for better visualising the inclination of the surfaces.

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