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Uticaj brzine rezanja i dubine reza na geometriju prednje linije reza pri obradi abrazivnim vodenim mlazom

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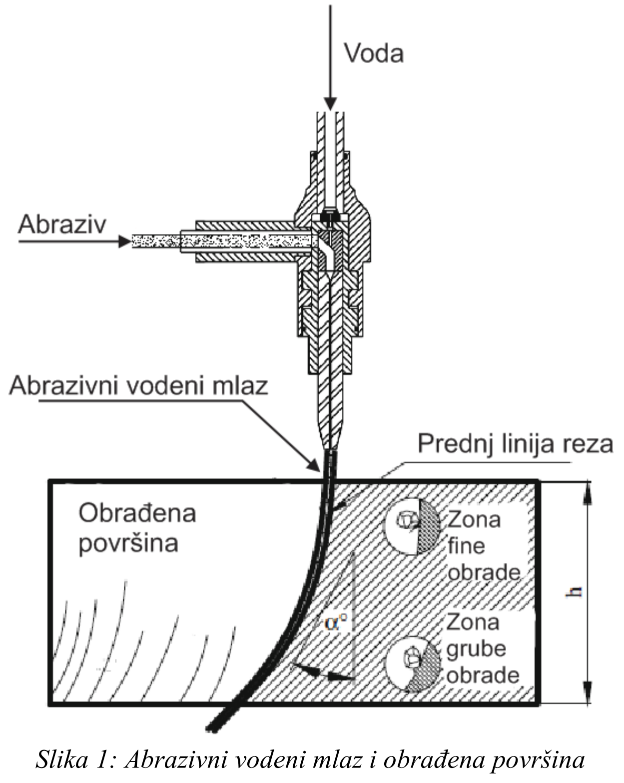
Obrada abrazivnim vodenim mlazom je nekonvencionalni postupak obrade koji se danas sve više primenjuje. Pogodan je za sečenje elemenata složenih dvodimenzionalnih oblika i za skoro sve vrste materijala. Osnovni nedostatak ovog postupka obrade je velika razlika u kvalitetu obrađene površine, po dubini reza, odstupanje reza od vertikalne linije i pojava zakrivljenih linija na obrađenoj površini. Zakrivljene linije na obrađenoj površini predstavljaju putanje abrazivnog vodenog mlaza kroz materijal i mogu se posmatrati kao prednja linija reza. Njihova pojava može prouzrokovati različite greške pri spajanju zatvorenih kontura pri sečenju. Takođe mogu izazvati greške pri sečenju uglova. Cilj ovog rada je da istraži uticaj brzine kretanja rezne glave i dubine reza na geometriju prednje linije reza, odnosno njeno odstupanje od idealne, vertikalne linije. Eksperimenti su vršeni na uzorcima od legure aluminijuma AA 6060 (EN AW-6060; ISO AlMgSi) debljine 6 mm i 10 mm. Na uzorcima su merena odstupanja prednje linije reza od idealne na različitim dubinama reza. Na osnovu dobijenih rezultata definisan je njihov uticaj na odstupanje prednje linije reza.

Ključne reči: Obrada abrazivnim vodenim mlazom, geometrija prednje linije reza

1. UVOD

Obrada abrazivnim vodenim mlazom je nekonvencionalni postupak obrade novijeg datuma. Najčešće operacije koje se ovim postupkom obrade mogu izvoditi su: sečenje, poliranje površina, čišćenje površina itd. U svim slučajevima mehanizam obrade se zasniva na eroziji. Kod ovog postupka obrade, alat je abrazivni vodeni mlaz, tj. uzani mlaz vode velike brzine, nastao isticanjem kroz mlaznicu malog prečnika, kome su zatim dodate čestice abraziva.



Slika 1: Abrazivni vodeni mlaz i obrađena površina

Zadatak mlaza vode je da prenese kinetičku energiju na čestice abraziva. Prilikom obrade abrazivnim vodenim mlazom, na obrađenoj površini se javljaju tragovi koji su karakteristični za sve postupke obrade mlazom koncentrisane energije, slika1.

Osnovne prednosti ove obrade su te što ne dolazi do razvoja toplote u zoni rezanja i, u najvećem broju slučajeva, nije potrebno stezanje predmeta obrade. Glavni nedostatak ove obrade je velika razlika u hrapavosti obrađene površine u zavisnosti od dubine reza.

Gornji deo površine obrađene abrazivnim vodenim mlazom (sa strane ulaza mlaza) ima znatno manju hrapavost u odnosu na donji deo obrađene površine. Kraj gornjeg dela površine se obično naziva granica zone fine obrade. Nakon ove granice dolazi do sve izraženije pojave valovitosti i do sve veće hrapavosti obrađene površine, kao i do pojave zakrivljenih linija.

Ove zakrivljene linije su posledica skretanja (odstupanja od vertikalne linije) abrazivnog vodenog mlaza pri obradi i predstavljaju putanju abrazivnog vodenog mlaza kroz materijal tokom obrade. Do skretanja abrazivnog vodenog mlaza dolazi zbog kretanja rezne glave u odnosu na predmet obrade i zbog gubitka kinetičke energije abrazivnog vodenog mlaza tokom obrade [1].

Na slici 2 je prikazana površina obrađena abrazivnim vodenim mlazom i prednja linija reza, kao i idealna prednja linija reza.

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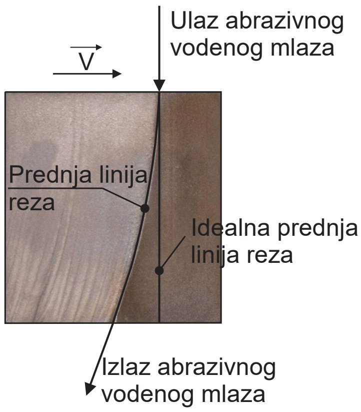


Slika 2: Prednja linija reza i idealna prednja linija reza

2. GEOMETRIJA PREDNJE LINIJE REZA

Na oblik prednje linije reza utiču parametri procesa obrade abrazivnim vodenim mlazom. Stepen uticaja pojedinih parametara je različit, ali najuticajniji od tih parametara su brzina kretanja rezne glave, radni pritisak, protok abraziva i dubina reza [1], [2].

Nekoliko autora se bavilo istraživanjem geometrije prednje linije reza. Raju i Ramulu [3], su utvrdili da je pojava zakrivljenih linija uslovljena promenom energija abrazivnog vodenog mlaza. Momber i Kovačević [1] su odstupanje prednje linije reza od idealne prave linije takođe objasnili gubitkom energije abrazivnog vodenog mlaza.

A.Akkurt [4] je aproksimirao prednju liniju reza polinomom drugog reda. Koeficijenti ovog polinoma su nezavisni od režima obrade i karakteristika materijala koji se obrađuje, tako da se može primeniti samo za tačno definisane uslove obrade određenog materijala. L.Hlavač [5] i B. Strnadel, L.Hlavač and L.Gembalova [6] su istraživali uticaj mehaničkih osobina materijala koji se obrađuje na ugao tangente na pradnju liniju reza. Uticaj režima obrade nije razmatran.

Svi ovi modeli se zasnivaju na merenju odstupanja prednje linije reza od idealne. Uticaj različitih parametara procesa obrade nije razmatran. Kao što je već pomenuto na odstupanje prednje linije reza utiče kretanje rezne glave u odnosu na predmet obrade i gubitak kinetičke energije abrazivnog vodenog mlaza. Na kinetičku energiju abrazivnog vodenog mlaza utiču radni pritisak, protok abraziva, prečnik abrazivne i vodene mlaznice itd. Zbog toga je cilj ovog rada da ispita uticaj brzine kretanja rezne glave na odstupanje prednje linije reza. Takođe, cilj je bio da se utvrdi da li i debljina obratka ima uticaja na odstupanje prednje linije reza ili je odstupanje na istim dubinama reza isto, nezavisno od ukupne debljine obratka.

3. EKSPERIMENTALNA ISTRAŽIVANJA

U ovom radu je ispitivan uticaj brzine kretanja rezne glave i dubine reza na geometriju prednje linije reza. Eksperimenti su vršeni na mašini PTV-3.8/60, koja ima hidraulični pojačavač pritiska H2O-JET tip 60K, čiji je maksimalni radni pritisak 413 [MPa]. Prečnik vodene mlaznice je 0.254[mm]. Abrazivna mlaznica je ROCTEC 100 prečnika 1.02 [mm]. Kao abraziv je korišćen GARNET ≠80 čija je prosečna veličina zrma 0.27 [mm], slika3.

Slika 3: Obrada uzoraka

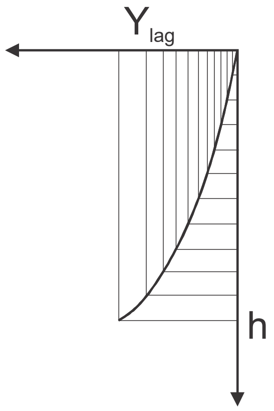
Prilikom eksperimanata radni pritisak je bio 413 [MPa] a protok abraziva 400 [g/min]. Rastojanje rezne glave od površine predmeta obrade je bilo 2[mm]. Materijal koji je obrađivan je legura aluminijuma AA 6060 (EN AW-6060; ISO AlMgSi). Sečeni su uzorci debljine 6 i 10 milimetara sa različitim brzinama kretanja rezne glave.

Brzina rezanja je varairana tokom eksperimenta u opsegu od 200 [mm/min] do 1000 [mm/min]. Izgled tako dobijenih uzoraka je dat u tabeli 1.

Tabela 1. Izgled uzoraka

Brzina rezanja V [mm/min]	Debljina uzorka s [mm]	
	s = 6 mm	s = 10 mm
200		
300		
400		
500		
800		
1000		

Da bi se definisala geometrija prednje linije reza, na mikroskopu su izmerena odstupanja prednje linije reza od idealne linije, na svaki milimetar dubine reza slika 4.



Slika 4:Način merenja geometrije prednje linije reza

Ovako dobijeni rezultati su prikazani u tabelama 2 i 3. Za uzorke debljine 6 [mm] i 10 [mm] dobijenim obradom pri brzinu kretanja rezne glave od 200 [mm/min] nije bilo moguće izmeriti odstupanje prednje linije reza od vertikalne linije jer se nisu uočavale zakrivljene linije.

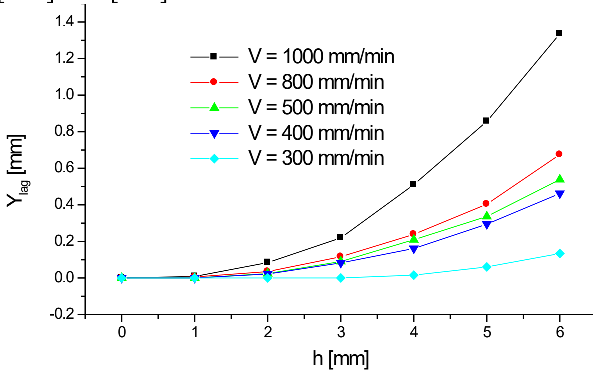
Tabela 2. Odstupanje prednje linije reza za uzorak debjjine 6 mm

Dubina reza	Brzina rezanja V [mm/min]				
h[mm]	1000	800	500	400	300
0	0	0	0	0	0
1	0.009	0.006	0	0	0
2	0.084	0.035	0.024	0.021	0
3	0.219	0.116	0.090	0.083	0
4	0.511	0.239	0.209	0.161	0.016
5	0.856	0.404	0.337	0.294	0.060
6	1.335	0.675	0.538	0.462	0.134

Tabela 3. Odstupanje prednje linije reza za uzorak debjjine 10 mm

Dubina reza	Brzina rezanja V [mm/min]				
h[mm]	1000	800	500	400	300
0	0	0	0	0	0
1	0.036	0.019	0.015	0.014	0
2	0.127	0.122	0.076	0.051	0
3	0.301	0.274	0.132	0.066	0.022
4	0.5342	0.384	0.219	0.0761	0.028
5	0.815	0.527	0.347	0.102	0.035
6	1.147	0.78	0.497	0.171	0.055
7	1.53	1.15	0.677	0.306	0.104
8	1.964	1.55	0.915	0.48	0.1935
9	2.503	2.024	1.174	0.644	0.335
10	3.122	2.557	1.425	0.804	0.565

Na slici 5 prikazani su dijagrami koji pokazuju zavisnost geometrije prednje linije reza od brzine kretanja rezne glave i dubine reza za uzorke debljine 6 [mm] i 10 [mm].



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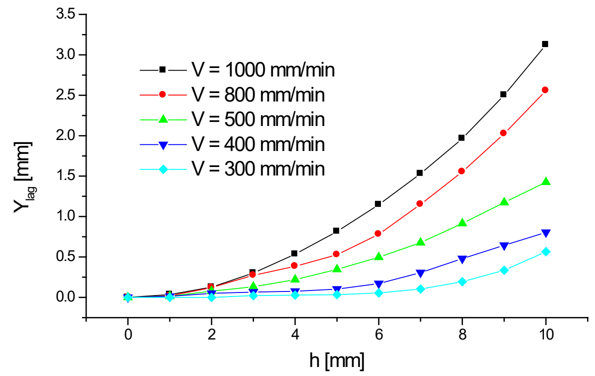
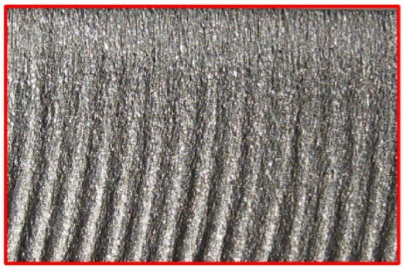


b)

Slika 5: Dijagram odstupanja prednje linije reza za uzorke debljine 6 [mm]; b) za uzorke debljine 10 [mm]

Na slici 4 su uporedo prikazani uzorci debljine 10 [mm] i 6 [mm] dobijeni pri obradi sa brzinom kretanja rezne glave od 500 [mm/min]. Može se uočiti poklapanje prednje linije reza na istoj dubini reza, na oba uzorka, bez obzira na njihovu debljinu.



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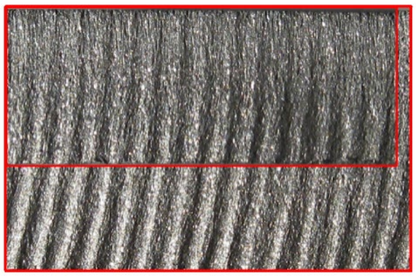
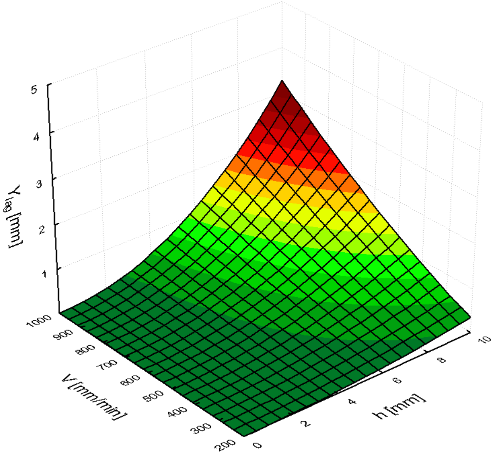


b)

Slika 6: Poređenje prednje linije reza za različite uzorke a) uzorak debljine 10 [mm] i b) uzorci debljine 6 [mm] i 10 [mm]

Na osnovu svih izmerenih vrednosti dat je dijagram promene odstupanja prednje linije reza od idealne prave linije u zavisnosti od brzine kretanja rezne glave i dubine reza, slika 7.



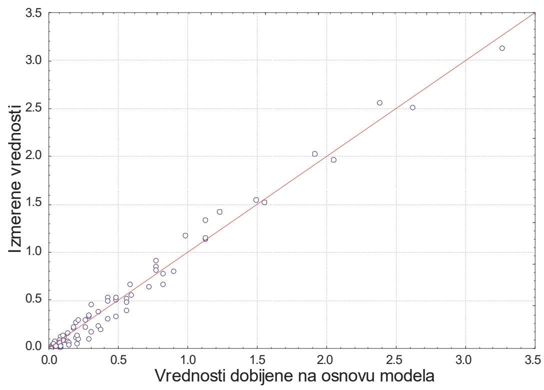
Slika 7: Dijagram promene odstupanja prednje linije reza

Matematički model koji opisuje uticaj brzine kretanja rezne glave i dubine reza na odstupanje prednje linije reza od idealne linije je predstavljen formulom 1:

$$Y_{lag} = 0{,}162 \cdot 10^{-5} \cdot h^{2{,}081} \cdot v^{1{,}40785} \qquad (1)$$

Ovaj model ima dobro poklapanje sa izmerenim vrednostima, što pokazuje i podatak da je koeficijent korelacije R=0.9913679.

Na slici 8 je prikazan odnos izmerenih vrednosti odtupanja prednje linije reza i onih dobijenih na osnovu modela datog formulom 1.



Slika 8: Odnos izmerenih vrednosti odstupanja prednje linije reza i vrednosti dobijenih na osnovu modela

4. ZAKLJUČAK

Rad je rezultat eksperimentalnog istraživanja uticaja brzine kretanja rezne glave i dubine reza na geometriju prednje linije reza. Na osnovu dobijenih rezultata može se zaključiti da sa porastom brzine kretanja rezne glave dolazi do povećanja odstupanja prednje linije reza od idealne. Takođe se može zaključiti da što je dubina reza veća, veće je i odstupanje prednje linije reza od idealne.

Poređenjem uzoraka različitih debljina, dobijenih pri istim brzinama kretanja rezne glave, može se uočiti da se prednje linije reza u velikoj meri poklapaju. Na osnovu toga se može zaključiti da debljina uzorka ne utiče na geometriju prednje linije reza, već je odstupanje prednje linije reza od idealne isto na istim dubinama reza za uzorke različite debljine koji su obrađeni sa istim režimima obrade. Vrednosti za odstupanje prednje linije reza dobijene merenjem i na osnovu matematičkog modela imaju veoma dobro poklapanje.

ZAHVALNICA

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Effect of Traverse Speed on Cut Front Geometry in Abrasive Water Jet Machining

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Abrasive water jet machining is an unconventional machining process, which is increasingly being used. It is suitable for cutting complex contoured elements, in all types of materials. The major disadvantages of this machining technique are ununiform quality of the machined surface at different depths of cut, lagging of the cut front of the machined surface from the vertical plane and the phenomenon of striation patterns on the cut surface. The striation patterns on machined surface are the trail of the abrasive water jet through the material, and as such, they represents the cut front. Striation may result in different flaws occurring at cutting closed contours and may cause irregularities at cutting angles. The objective of this paper was to determine traverse speed and depth of cut effect on the cut front geometry i.e. on the striation geometry. The experiments were carried out on 6 mm and 10 mm thick samples of aluminum alloy AA 6060 (EN AW-6060; ISO AlMgSi). Samples were machined with several traverse speeds. The lagging of the cut front, at different depths of cut, was measured and analyzed. The obtained results enabled us to define the influence of traverse speed on striation geometry.

Keywords: abrasive water jet, cut front geometry, traverse speed

1. INTRODUCTION

Abrasive water jet machining is an unconventional and new technique. The most common operations performed by this technique are cutting, polishing, surface cleaning, etc. At all of these operations, the main material removal process is erosion. In abrasive water jet machining the tool is small diameter, high speed water jet mixed with abrasive particles. The high speed water jet is generated by flowing the high pressure water through a small diameter nozzle.

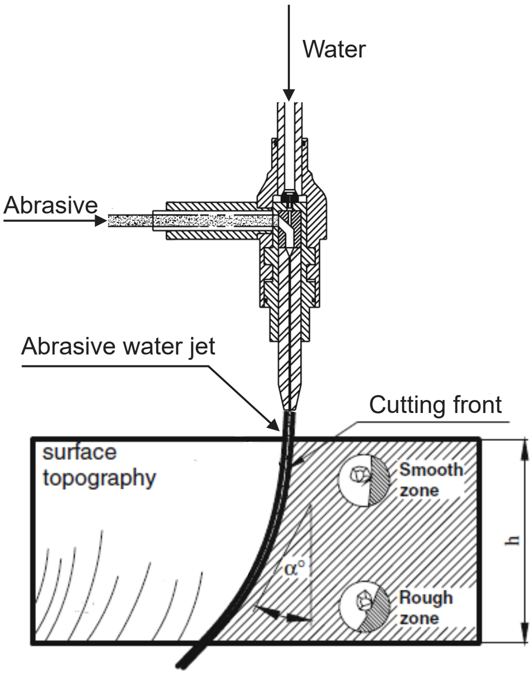

Figure 1. Abrasive water jet and machined surface

The water jet transfers the kinetic energy on abrasive particles which are distributed over a machined surface. The result of this process is a machined surface with striations, typical for all machining processes with high-energy jet, figure 1.

The major advantage of this machining process is that no heat developed in the cutting zone and fact that in the most of the cases, while machining the workpiece material, no clamping is required. On the other hand, the main disadvantage of this machining process is that roughness of the machined surface significantly varies at different depths of cut.

The upper zone of the surface machined with the abrasive water jet (near the jet entrance) is significantly smoother than the lower zone which is rough, wavy, with striations. The upper zone of the machined surface is generally known as a limit of fine machining zone. Bellow this line waviness is more prominent – the machined surface is more rough and accompanied with striations.

These striations are the result of lagging of the abrasive water jet (lagging from the vertical plane) during machining and they represent the cutting path of the abrasive water jet through the material.

The lagging of the abrasive water jet is consequence of the cutting head movement relative to the workpiece as well as due to the loss of kinetic energy of the abrasive water jet during machining [1].

Figure 2 shows the surface machined by abrasive water jet, cut front and ideal cut front geometry

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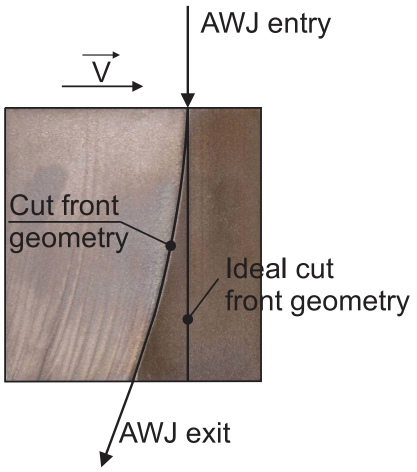


Figure 2. Cut front and ideal cut front

2. CUT FRONT GEOMETRY

The shape of the cut front is determined by machining parameters of abrasive water jet process. Machining parameters influence on the shape of the cut front in a different degree. However, the most influential are traverse speed, operating pressure, abrasive flow rate and depth of cut [1], [2].

Several authors have studied the cut front geometry. Raju and Ramulu [3] reported that the appearance of striation is consequence of change in AWJ (abrasive water jet) cutting energy. Momber and Kovačević [1] also explained the cut front lagging with the loss of energy of abrasive water jet during machining.

In his work, A. Akkurt [4] approximated the cut front geometry with the second order polynomial. Coefficients of this polynomial are independent of the abrasive water jet machining parameters and characteristics of the workpiece material, hence it can be applied only to precisely determined machining parameters, and for machining of a particular material. L. Hlavač [5] and B. Strnadel, L. Hlavač and L. Gembalova [6] investigated the effect of mechanical properties of the machined material on the tangent angle setting on the cut front geometry. The influence of the machining parameters was not analyzed.

All these models are based on measuring of the cut front lagging from the ideal plane. The effect of the different machining parameters was not studied. As mentioned above, the cut front geometry is the most affected by traverse speed, relative to the object of machining, and the loss of kinetic energy of the abrasive water jet. Then the most influential are operating pressure, abrasive flow rate, abrasive and water nozzle diameter, etc. Therefore, the objective of this paper was to study the influence of traverse speed on the cut front geometry. The paper also investigate the workpiece material thickness influence on the cut front geometry, or whether the lag is identical at all depths of cut, regardless of the total thickness of the material machined, for the same material.

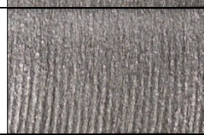
3. EXPERIMENTAL STUDIES

This paper examines the influence of traverse speed and depth of cut on the cut front geometry. The experiments were performed on PTV-3.8/60 machine, with H_2O-JET type 60K hydraulic pressure intensifier with 413 [MPa] maximum pressure. Water nozzle diameter is 0.254 [mm]. Used abrasive nozzle was ROCTEC100, diameter 1.02 [mm]. The abrasive used for machining of workpieces was GARNET≠80 with 0.27 [mm] average particle size, figure 3.

Figure 3: Machining of the samples

During the experiment, the operating pressure setting and abrasive flow rate were 413 [MPa] and 400 [g/min] respectively. Cutting head was set at 2 mm distance from the surface of the machined material. The workpiece material was aluminum alloy AA 6060 (EN AW-6060; ISO AlMgSi), while samples were 6 and 10 [mm] thick. Traverse speed was varied in the experiment, in the range from 200 [mm/min] to 1000 [mm/min]. Table 1 presents the images of the surfaces of the samples machined under the conditions above.

Table 1. Images of machined samples

Traverse speed V [mm/min]	Thickness of sample s [mm]	
	s = 6 mm	s = 10 mm
200		
300		
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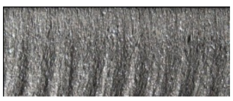
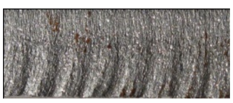
500		
800		
1000		

In order to determine the cut front geometry, the microscope was used to measure the lagging of the cut front geometry from the ideal cut front line at every millimeter of the depth of cut, as shown in the figure 4.

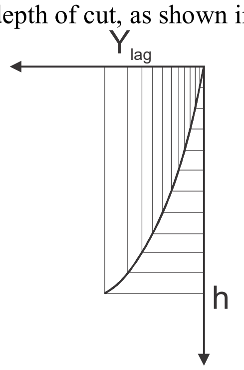


Figure 4: Method of measuring cut front geometry

Results obtained in this manner are presented in Tables 2 and 3. For 6 mm and 10 [mm] thick samples, machined at the traverse speed of 200 [mm/min], it was not possible to determine the cut front lagging, because no striation patterns were observed.

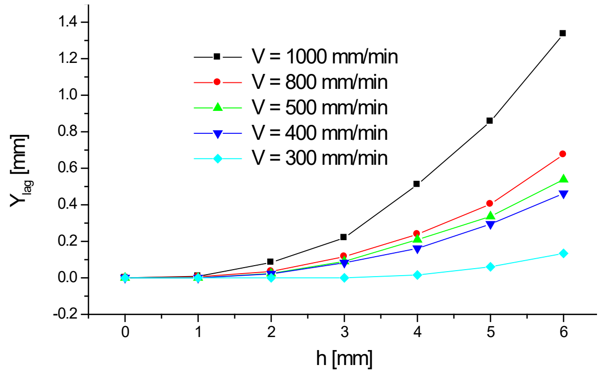
Table 2. Cut front lagging in 6 mm thick samples

Depth of cut	Traverse speed V [mm/min]				
h[mm]	1000	800	500	400	300
0	0	0	0	0	0
1	0.009	0.006	0	0	0
2	0.084	0.035	0.024	0.021	0
3	0.219	0.116	0.090	0.083	0
4	0.511	0.239	0.209	0.161	0.016
5	0.856	0.404	0.337	0.294	0.060
6	1.335	0.675	0.538	0.462	0.134

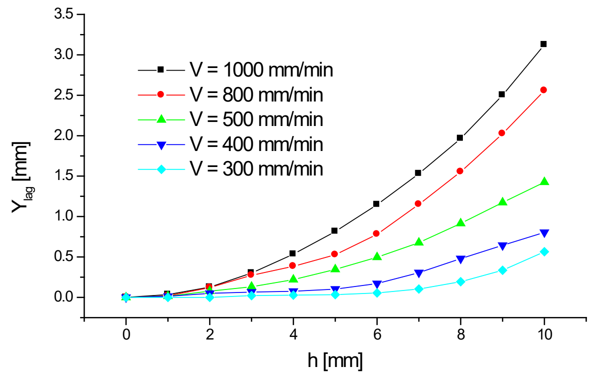
Table 3. Cut front lagging in 10 mm thick samples

Depth of cut	Traverse speed V [mm/min]				
h[mm]	1000	800	500	400	300
0	0	0	0	0	0
1	0.036	0.019	0.015	0.014	0
2	0.127	0.122	0.076	0.051	0
3	0.301	0.274	0.132	0.066	0.022
4	0.5342	0.384	0.219	0.0761	0.028
5	0.815	0.527	0.347	0.102	0.035
6	1.147	0.78	0.497	0.171	0.055
7	1.53	1.15	0.677	0.306	0.104
8	1.964	1.55	0.915	0.48	0.1935
9	2.503	2.024	1.174	0.644	0.335
10	3.122	2.557	1.425	0.804	0.565

Figure 5 presents graphs which are showing the correlation between the cut front geometry, traverse speed and depth of cut (6 mm and 10 mm samples).



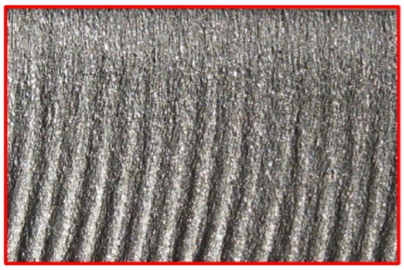
a)



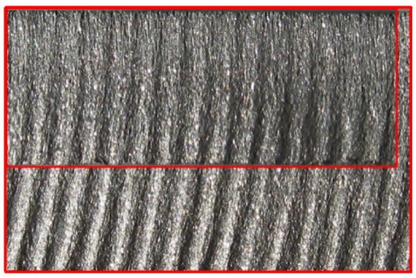
b)

Figure 5: Graph showing cut front geometry-lagging
a) 6[mm] thick samples; b) 10 [mm] samples

Figure 6 shows comparison of 10 mm and 6 mm thick samples machined with 500 mm/min traverse speed. The figure implies correspondence of the cut front geometry at the same depth of cut in both samples, regardless of their thickness.



a)



b)

Figure 6: Comparison of cut front in machined samples of different thickness : a) 10 mm thick sample b) 6 mm and 10 mm thick samples

Diagram of machining traverse speed and depth of cut influence on jet lagging, figure 7, was created using the measured values.

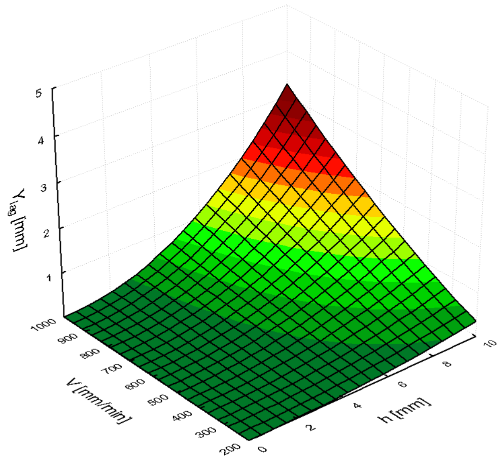


Figure 7: Graph showing change in cut front lagging

Mathematical model describing the influence of traverse speed and depth of cut on cut front geometry is given in equation 1:

$$Y_{lag} = 0{,}162 \cdot 10^{-5} \cdot h^{2{,}081} \cdot v^{1{,}40785} \tag{1}$$

This model shows good correlation with the measured values, which is confirmed with the correlation coefficient R=0.9913679.

Figure 8 presents the correlation between the measured values of the cut front lagging and those obtained by the model based on equation 1.

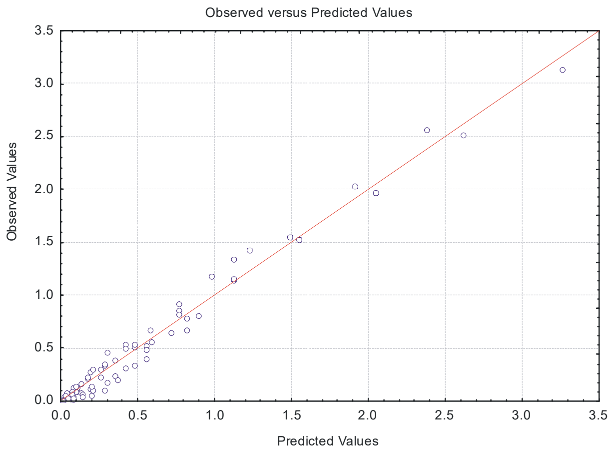


Figure 8: Correlation between values of cut front lag and those obtained by the model

4. CONCLUSION

The paper is the result of experimental study of the influence of traverse speed and depth of cut on cut front geometry. The obtained results show that the increase in traverse speed causes the increase in cut front lagging. Another conclusion is that the higher the depth of cut, the greater is the cut front lagging from the ideal plane.

The comparison of machined surfaces of the different thickness samples, obtained at identical traverse speeds, shows substantial correspondence, which indicates that thickness of a sample does not affect cut front geometry. The cut front lagging were the same at identical depths of cut in samples of different thickness, machined by identical machining parameters.

Cut front lagging values obtained by measuring and mathematical model imply high correlation.

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