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Techno-Economic Analysis of Abrasive Water-Jet Machining and Wire Electrical -Discharge Machining

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Nowadays, carefully selected technologies for material machining can significantly affect quality of machined surface and the cost of machining. Stainless steels are increasingly used in modem production. Austenitic stainless steels (type AISI 304 including Č 4580) make up over 50% of total world production of stainless steel. Several methods for machining of these materials are available in practice today. However, some types of machining cause the change in the material properties. Machined surface quality in the function of traverse speed and costs of the stated machining methods has been selected for comparative analysis of the machining methods. This paper presents an analysis of steel machining technology (4580 type of steel) with two different machining methods - abrasive water-jet and wire electrical-discharge machining. In addition, an economic analysis of the two machining methods has been conducted from the cost standpoint.

Tehno-ekonomska analiza obrade abrazivnim vodenim mlazom i elektroerozijske obrade žicom

Izvornoznanstveni rad

U današnje vrijeme, pažljiv izbor tehnologije obrade materijala znatno može uticati na kvalitetu obrađivane površine i trošak obrade. Nehrđajući čelici se danas sve više koriste u suvremenoj proizvodnji. Od ukupne svjetske proizvodnje nehrđajućih čelika, čak 50% čine austenitni nehrđajući čelici iz grupe AISI 304, u koju spada i čelik Č 4580. Danas je u praksi dostupno nekoliko metoda za obradu ovih materijala. Međutim, kod nekih vrsta obrade dolazi do promjene karakteristika ovih materijala. Za uporednu analizu postupaka obrade izabrana je kvaliteta obrađene površine u funkciji brzine rezanja i troškova navedenih postupaka obrade. U ovom radu je prikazana analiza obrada čelika Č 4580 pomoću dva različita postupka obrade - abrazivnim vodenim mlazom i elektroerozijskom obradom žicom.

1. Introduction

Due to increasingly rapid development of new technologies, it is difficult to choose the right technology for the machining of some material. When selecting the appropriate technology, the greatest effect on the decision has the quality of the machined surface and the time required to design a product. Machined surface quality, during cutting process, is a complex concept that involves changes in material properties, structure and

Symbols/Oznake

$C_{awj,h}$	- costs of machining with abrasive water-jet (AWJM) - ukupni troškovi obrade abrazivnim vodenim mlazom (AWJ)	c_a	- the price of abrasive per unit - cijena abraziva po jedinici
C_I	- the total costs of investment - ukupni troškovi investicije	T_n	- the useful life mixing of jets - vijek uporabe miješanja mlaznice
C_e	- the total price of electricity - ukupni troškovi energije	T_0	- the useful life of water jet - vijek uporabe vodene mlaznice
C_w	- the total price of water, - ukupni troškovi vode	M	- total costs of maintenance per year - ukupni godišnji troškovi održavanja vodene mlaznice
C_a	- the total price of abrasive - ukupni troškovi abraziva	L_a	- number of working hours - broj radnih sati
C_n	- the total price of mixing jets - ukupni troškovi miješanja mlaznica	$C_{WEDM,h}$	- costs of the wire electrical discharge machining - troškovi obrade elektroerozionom obradom s žicom (EDM)
C_o	- the total price of water-jet - ukupni troškovi vodene mlaznice	φ	- diameter of the wire - promjer žice
C_v	- the total maintenance costs - ukupni troškovi održavanja	ν_w	- speed of rewinding wire - brzina premotavanja žice
I	- investment - iznos investicije	ρ	- brass wire density - gustoća žice
L_I	- the useful life - vijek uporabe vodene mlaznice	t_k	- the time per unit - vrijeme po jedinici
P	- power of plant - snaga pogona	t_{pz}	- the preparatory and final time - pripremno završno vrijeme
c_e	- the price of electricity per unit - cijena energije po jedinici	t_p	- a subsidiary time - pomoćno vrijeme
m_w	- water flow - protok vode	t_g	- effective cutting time (the time of the mainly machining) - vrijeme efektivnog rezanja (glavno vrijeme obrade)
c_w	- the price of water per unit - cijena vode po jedinici		
m_a	- the flow of abrasive - protok abraziva	t_d	- addition time - dodatno vrijeme

size of the defect layer, machined surface roughness and geometrical characteristics of the cut. Sometimes it is impossible to satisfy all these criteria, therefore some of them are neglected depending on the required output.

The quality of machining can be evaluated through measuring certain characteristics such as machined surface roughness, through satisfying demands of tolerance, parallelism of the cut sides and their normality to the base surface. These parameters must be taken into account when comparing two or more machining methods.

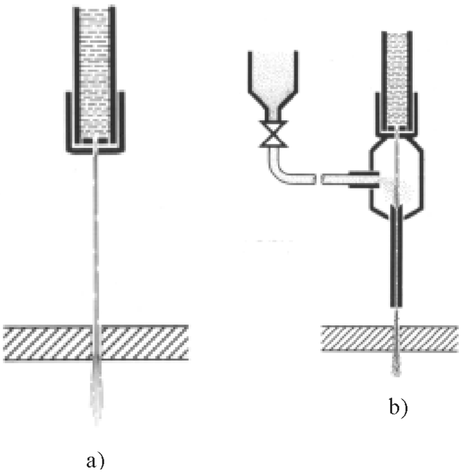
Nowadays, an increasing number of researches in the field of unconventional treatments is carried out so that the quickest, cheapest and best machining method can be achieved. However, it is mostly believed that abrasive water-jet machining can be applicable for rough machining, whereas wire electrical-discharge machining is mainly used for fine, finish machining. A very small number of researchers have analyzed the relation between these two surface qualities obtained through the machining methods. Some of the existing researches are research carried out by Akkurt A. [1], research carried out by company *MC Machinery Systems, Inc*., and research carried out by manufacturer *Mitsubishi EDM* and *Waterjet Powered by Mitsubishi Electric*. Therefore, the objective of this paper is to show that both abrasive water-jet machining and wire electric discharge machining can bring about the same quality of machining, so that the two machining (AWJM and WEDM) can also be compared with the appropriate economic parameters.

This paper presents the conducted abrasive water-jet (AWJ) and *wire* electrical discharge machining (WEDM). Abrasive water-jet machining and electrical discharge machining are two methods for cutting of the materials with greatest future prospects. At high traverse speeds these two machining methods make it possible to obtain parts of complex contours and precise design. In addition, these methods enable machining of different materials, either metallic or nonmetallic.

2. Abrasive water-jet machining

Continuous development of high-pressure water jet machining started in the first half of the twentieth century. *The addition of abrasives in the water-jet* significantly widened the range of materials being machined. Furthermore, higher traverse speed, greater accuracy of machining and better surface quality, were reached.

The most common operations carried out through this type of machining are: cutting, surface polishing, surface cleaning, etc.. In all cases, the machining mechanism is based on erosion. A great advantage of the machining method is that no significant temperature increase occurs in the machining zone. A schematic diagram of water-jet machining without abrasive is shown in Figure 1 a), whereas abrasive water-jet machining is displayed in Figure 1 b).



b)

a)

Figure 1. Scheme of the processing without abrasive water-jet a) and with abrasive water-jet b)

Slika 1. Shematski prikaz obrade vodenim mlazom bez abraziva a) i sa abrazivom b)

Modern installations for abrasive water-jet machining function even at water pressure over 5000 bar, whereas the water-jet reaches the speed of 1400 m/s.

Abrasive water-jet machining is based on erosion which presents the basic mechanism of material removal of the workpiece. Workpiece material removal is a continuous process beginning with the *impact* between the *abrasive particle* and the material, which causes the removal of a very small amount of the workpiece material. The number of the abrasive particles striking the workpiece material in one second amounts to ten thousand. [3].

3. Wire electrical discharge machining

Wire electrical discharge machining emerged in the late 1960s. At the moment it appeared, it presented a revolution in the mechanical industry. Wire electrical discharge machining has many advantages. This method enables machining of all the materials with electrical conductivity, regardless of their mechanical properties such as hardness and brittleness. During the machining process there is no contact between wire and the workpiece, so that no pressure or mechanical stress occurs on the workpiece. Furthermore, the necessary force holding the workpiece is very small, which is very suitable for machining of small or breakable objects. Wire electrical discharge machining leaves no traces of tool on the uniform machined surface. Parts that have complex geometry and close tolerances can be easily made using this method.

The basic mechanism of wire electrical discharge machining is erosion. Erosion occurs due to heating of the material on machined surface, melting and evaporation of the material. Material heating is a consequence of the heat released when the sparkles occur between a wire electrode (typically thinner than 0.3mm) and the workpiece through deionized water. Deionized water is used as a dielectric and it surrounds the workpiece [2].

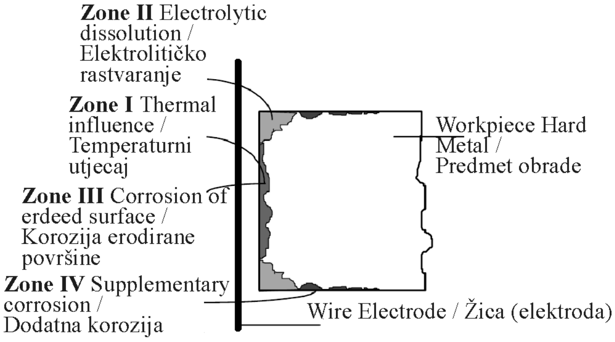


Figure 2. Characteristic zones on the hard metal machined surface [2]

Slika 2. Karakteristične zone na obrađenoj površini [2]

Figure 2 shows the characteristic zones on the hard metal surface machined through wire electrical discharge machining.

Zone I is the heat-affected zone. It is the result of electrical discharge and has a negative effect on the machined surface quality. It is in this zone that surface stress and micro fractures occur.

Zone II is the zone of electrolytic dissolution. *During* the machining process a rather intense *electric field* is formed by the active area *between* the *anode - workpiece and cathode – wire.* This phenomenon brings about electrochemical reactions which can cause the dissolution of workpiece material.

Zone III presents the corrosion of eroded surface

Zone IV is the zone where additional corrosion can occur.

This is a general classification into zones. Nevertheless, the presence of certain zones on the machined surface depends on the type of the machined material and parameters of a cutting mode.

4. Machined surface

Figure 3 shows the appearance of the surface machined with abrasive water-jet whereas Figure 4 shows the appearance of the surface machined with electrical-discharge machining.

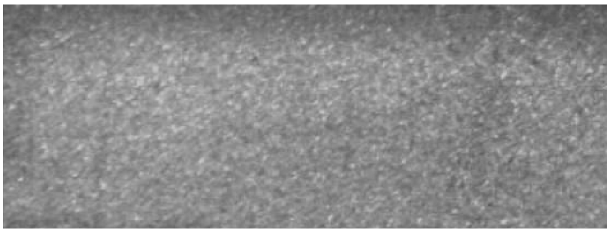


Figure 3. Surface machined with abrasive water-jet

Slika 3. Površina obrađena abrazivnim vodenim mlazom

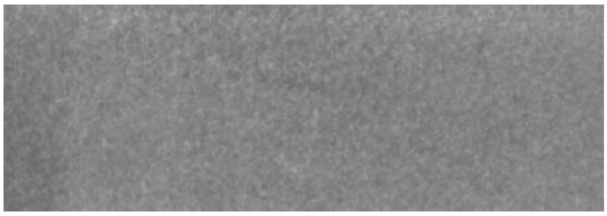


Figure 4. Surface machined with electrical-discharge machining

Slika 4. Površina obrađena elektroerozionom obradom

The two Figures show the appearance of the surfaces obtained during the research. The surface obtained with abrasive water-jet machining at the highest traverse speed (105 mm/min) during research is shown in Figure 3, whereas the surface obtained with wire electrical discharge machining (at traverse speed of 0.8 mm/min) is displayed in the Figure 4.

During abrasive water-jet machining, machined surface quality is most often classified into one of 5 characteristic groups, Figure 5. The machined surface which is at Q1 quality level is characteristic for rough cutting of workpieces at high traverse speed. An additional force is necessary to bring about the separation of the cut workpieces. The machined surface requires further machining.

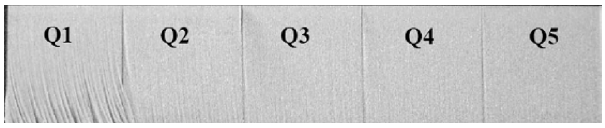


Figure 5. Five characteristic of machined surface quality

Slika 5. Pet karakterističnih kvaliteta obrađene površine

Q2 machined surface quality is obtained during the machining process of workpiece (the parts are completely separated), and in most cases further machining is necessary. Q3 machined surface quality is more demanding than the previous two. In order to reach high quality of the machined surface it is necessary to adjust traverse speed, operating pressure, abrasive water jet speed and the amount of the abrasive material. Such machining modes enable the production of the certain fixed parts, i.e. further machining is not necessary depending on their purpose. Q4 machined surface quality is higher than Q3 machined surface quality. At this quality level, many parts can be designed without additional machining. Q5 machined surface quality is very high and it is achieved in high accuracy parts but at very low traverse speeds wherein the time per unit is not the criterion for the selection of the cutting mode. The width of the cut is constant at both upper and lower parts of the machined surface. Many scientific papers concerning the evaluation of the micro-geometrical features of abrasive waterjet cutting are available [4-6].

On the surfaces machined with abrasive water-jet in almost all stated surface qualities, curved lines typical for abrasive water-jet machining can be detected. The lines in the upper zone of the machined surface are almost vertical, whereas in the lower zone they are curved. The upper zone of the surface machined with abrasive water-jet refers to the basic machining zone (jet entry side). The curved lines can be more easily discerned on the surfaces in the lower qualities (Q1 and Q2) which occur during machining at high traverse speeds. This phenomenon can be related to the jet loss of energy during the cutting process, i.e. retardation of the cutting front of the water-jet in material. Retardation of the cutting front shows the jet direction through workpiece material. Retardation of the cutting front and loss of its energy bring about the change of quality of the machined surface, i.e. the change of the roughness of the machined surface for different depths of the cut, Figure 6.

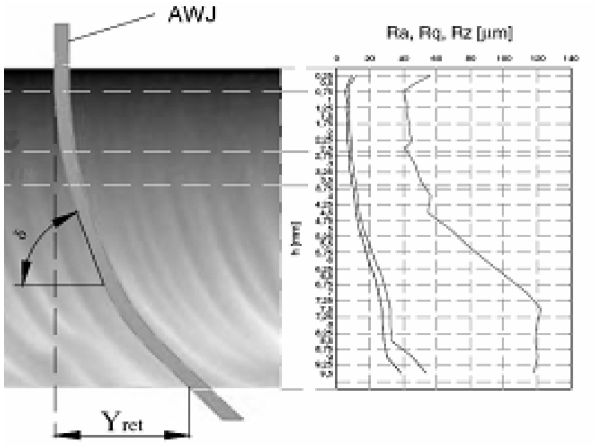


Figure 6. Change of surface roughness, depending on the depth of cutting [4]

Slika 6. Promena hrapavosti obrađene površine u zavisnosti od dubine rezanja [4]

During the machining in Q5 quality curved lines cannot be detected.

In contrast to abrasive water-jet machining, during wire electrical discharge machining neither lines on the machined surface nor wire traces can be detected.

As can be seen in Figure 7, during wire electrical discharge machining, large surface irregularities do not occur on the machined surface. Machined surface roughness is constant over the entire surface. Nevertheless, as distinguished from abrasive water-jet machining where no heat-affected zone occurs, during wire electrical discharge machining the effect of heat-affected zone can be evidenced.

Retention of the dissolved materials having remained in the machining zone is carried out in this zone. This phenomenon and high temperature effect significantly change the metallurgical characteristics of the machined material. Figure 8 shows the microstructure of Č 4580 steel without machining (a), after abrasive water-jet machining (b) and after wire electrical discharge machining (c) [1].

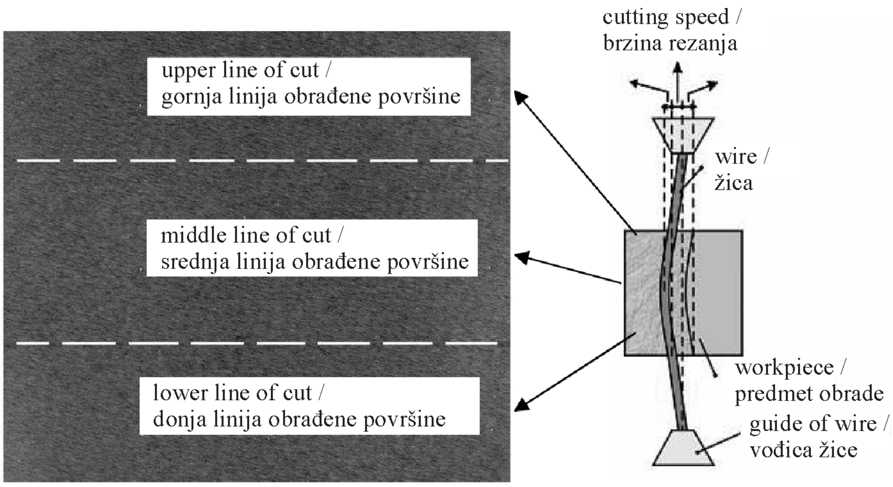
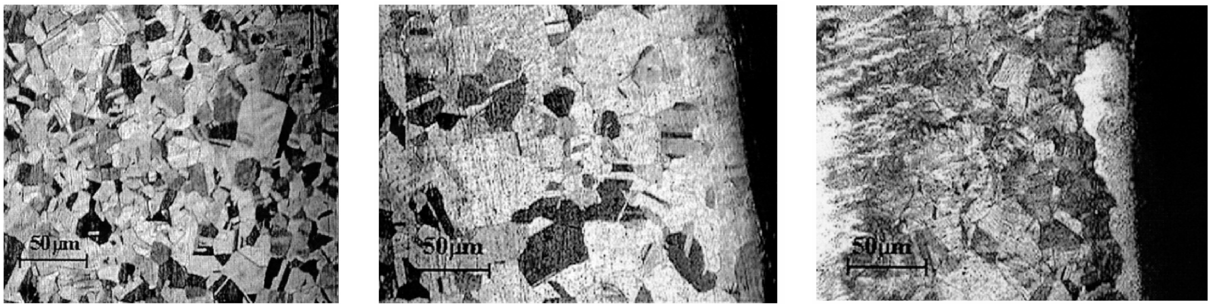


Figure 7. Surface appearance machined with wire electrical discharge machining [7]

Slika 7. Izgled površine obrađene elektroerozionom obradom sa žicom [5]



a) b) c)

Figure 8. The microstructure of steel C 4580 without the machining (a), after the machining by abrasive waterjet (b) and after wire electrical discharge machining (c) [1]

Slika 8. Mikrosrtuktura čelika C 4580 bez obrade(a), nakon obrade abrazivnim vodenim mlazom(b) i nakon elektroerozione obrade sa žicom(c)

5. Experimental research

In this paper we analyzed the quality of the machined surface of Č 4580 (10mm wide) stainless steel during two different machining methods: abrasive water-jet machining and wire electrical discharge machining. Since wire electrical discharge machining enables no significant variations in the value of machining parameters, only one sample with recommended machining parameters has been made. In abrasive water-jet machining technology five samples have been made at different traverse speed, while operating pressure and abrasive flow were constant. Samples 1 and 2 were machined at speeds lower than recommended speed, sample 3 at the recommended speed, while samples 4 and 5 were machined at higher speed than the recommended speed value. Abrasive water-jet machining was carried out using PTV Water jet machine, Figure 9. Wire electrical discharge machining was carried out using spark erosion machine (FANUC TAPE CUT-MODEL H), Figure 10.

Figure 9. PTV Water jet

Slika 9. PTV Water jet

Figure 10. Spark erosion machine ANUC TAPE CUT-MODEL H

Slika 10. Erozimat FANUC TAPE CUT-MODEL H

Five samples of Č4580 material were made using abrasive water-jet machine. Sample 1 was machined at traverse speed of 25mm/min, sample 2 at speed of 45mm/min, sample 3 at speed of 65mm/min which simultaneously presents the recommended value of traverse speed for machining at the highest quality level (Q5). Sample 4 was machined at traverse speed of 85mm/min whereas sample 5 was machined at speed of 105mm/min. Abrasive flow and operating pressure were held constant for all samples: Qa=350g/min i p=4130bar. A sample of the same Č4580 material was made using spark erosion machine at the recommended value of traverse speed of 0.8 mm/min, sample 6. Wire speed was Vw=60mm/s, and the wire thickness was 0.2mm. All remaining machining parameters were constant in both machining methods.

Roughness parameter (Ra) was measured on each sample. The parameters were measured at five places along the length of the sample and at three places along the height of the sample, as shown in Figure 11.

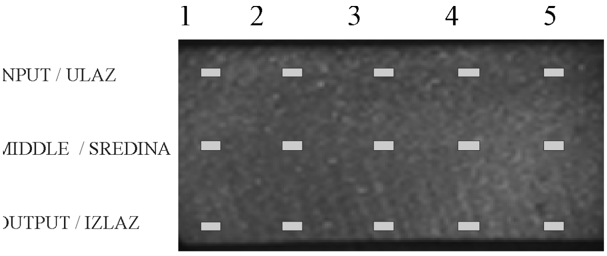


Figure 11. Measuring points in the machined sample surface

Slika 11. Merna mesta po obrađenoj površini uzorka

According to the all measured values, the mean value of Ra parameter (Rasr) was calculated and this value was accepted as adequate for the appropriate sample. Roughness was measured with roughness meter PERTHOMETER S5P.

5.1. Research results

The following table shows the change in value of roughness parameter (Rasr) on the samples depending on traverse speed.

Table 1. Change of the value of samples roughness Ra_{sr} depending on the speed of cutting.

Tabela 1. Promena vrednosti parametra hrapavosti Rasr na uzorcima u zavisnosti od brzine rezanja.

Sample / Uzorak	Label / Oznaka	Speed of cutting / Brzina rezanja, V, mm/min	Ra_{sr}, μm
1.	AWJ-1	25	1.725
2.	AWJ-2	45	1.786
3.	AWJ-3	65	2.127
4.	AWJ-4	85	2.039
5.	AWJ-5	105	2.607
6.	WEDM	0.8	2.885

Figure 12 displays a comparative analysis of Rasr values depending on traverse speed during wire electrical discharge machining and abrasive water-jet machining. Rasr parameter value measured on a sample which was obtained during wire electrical discharge machining is shown as a straight line parallel to the x-axis in the diagram. It is set as a threshold value for Rasr parameter. Rasr parameter values obtained by measuring the samples that were obtained during abrasive water-jet machining are shown by a dark line in the diagram.

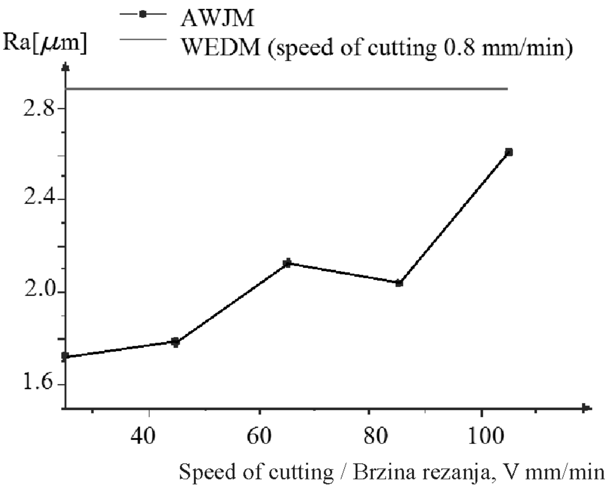


Figure 12. Comparative review of depending value Ra of cutting speed with the wire electrical discharge machining and machining by abrasive waterjet

Slika 12. Uporedni prikaz zavisnosti vrednosti Ra od brzine rezanja kod elektroerozione obrade sa žicom i obrade abrazivnim vodenim mlazom

The diagram shows that the value of Rasr parameter for samples obtained during abrasive water-jet machining increases with the increase in traverse speed. Nevertheless, the value of Rasr parameter at traverse speed of 105 mm / min does not exceed the values obtained at traverse speed of 0.8 mm / min.

6. Selection methodology for optimal design from economic standpoint

Taking into consideration the economic analysis of the two machining methods, it should be noted that the difference in cost accompanying the methods occurs primarily due to the use of this technology, i.e. devices. Labor and item costs (materials, raw materials) are assumed to be the same in both machining methods. Economic analysis is sustainable provided that both machining methods are used to achieve the same machined surface quality, i.e. the machined surface quality is satisfactory for every analyzed use of workpiece.

6.1. Method objective

When adopting a new technology of workpiece production, the main task of the development team is to create such a construction and technological documentation which will ensure that the machined workpiece (in production) can satisfy the requirements placed in front of it. The fact that the new workpiece can be designed in many ways and variations both constructionally and technologically makes the task of the development team more demanding. In addition, adopting a new workpiece production in a way that development team can design all the variations and consequently select the optimal option presents a very expensive procedure. Therefore, it is highly significant that during the adoption of a workpiece production, the workpiece development should be directed in the early phase to a small number of possible variants, preferably one. Thus, the costs of adopting a new technology can be significantly reduced.

Method which will be described below aims to determine an optimal variant of the workpiece i.e. a variant that has the lowest cost of production in an early phase of the workpiece development, and based on the estimation of production costs. The method is implemented at a time when the conceptual construction of the workpiece is defined: shape, measurements and material; process types applicable to the workpiece design are conceptually set.

The method is based on an estimation of the production costs. The authors have not found a comparison between two analyzed machining methods from an economic standpoint. The paper [13] presents a model for calculating the costs of design using both methods, as well as other non-conventional machining methods. The model has been improved and completed in this paper. Based on engineering experience and knowledge, it is possible that the estimation of production costs is sufficiently reliable and that its results are rather reliable.

6.2. Determining the cost of machining

6.2.1. Analysis of the cost of machining with abrasive water jet

Calculate costs of machining with abrasive water-jet (AWJM) conducted by (1) or (2).

$$C_{awj,h} = C_I + C_e + C_w + C_a + C_n + C_o + C_v, \quad (1)$$

$$C_{awj,h} = \frac{I}{L_I} + P \cdot c_e + m_w \cdot c_w + m_a \cdot c_a + \frac{c_n}{T_n} + \frac{c_o}{T_o} + \frac{M}{L_a}. \quad (2)$$

The subject of analysis is cutting already considered steel sample Č 4580 in length 100mm.

Cutting speed (adopted, the recommended value) v = 6 m/min.

Coefficient of quality (quality group) q =5.

Meaning of some labels and concrete values are given in Table 2 [13].

6.2.2. Analysis of the cost wire electrical discharge machining

Calculate cost of wire electrical discharge machining (WEDM) conducted by (3) or (4).

$$C_{WEDM,h} = C_I + C_E + C_W + C_V, \quad (3)$$

$$C_{WEDM,h} = \frac{I}{L_l} + P \cdot c_e + 0,41 \cdot c_w \cdot \varphi^2 \cdot v_w + \frac{M}{L_a}. \quad (4)$$

Meaning of some labels and concrete values are given in Table 2.

The wire costs C_w depending of thickness φ and wear wire speed v_w. Calculation of power wire is conducted by (5). In addition, we believe that the brass wire with a density ρ = 8700 kg/m³.

$$C_W = c_w \cdot V \cdot \rho = c_w \cdot \frac{\pi \cdot \varphi^2 \cdot 10^{-6}}{4} \cdot 60 \cdot v_w \cdot \rho = c_w \cdot \frac{\pi \cdot \varphi^2 \cdot 10^{-6}}{4} \cdot 60 \cdot v_w \cdot 8700 = 0,41 \cdot c_w \cdot \varphi^2 \cdot v_w. \quad (5)$$

Wear wire speed is:

- rough cutting

  steel: $h \le 5$
  v_w = 5 m/min
  50 mm < $h \le$ 150mm
  v_w = 3,5 m/min
  Al, Cu: 5 mm < $h \le$ 150 mm
  v_w = 4,9 m/min

- a fine cutting

  steel, Al, Cu: 5 mm < $h \le$ 150 mm
  v_w = 10 m/min

Table 2. Comparative costs analysis of the machining by abrasive waterjet and wire electrical discharge machining

Tabela 2. Uporedna analiza troškova obrade abrazivnim vodenim mlazom i elektroerozionom obradom sa žicom

Machining by abrasive waterjet / Obrada abrazivnim vodenim mlazom (AWJ)			**Wire electrical discharge machining / Elektroeroziona obrada s žicom (EDM)**		
Label / Oznaka	The term / Pojam	Value / Vrijednost	Label / Oznaka	The term / Pojam	Value / Vrijednost
I	Investment / Iznos investicije	200000 *E*	I	Investment / Iznos investicije	70000 *E*
L_1	The useful life / Vijek uporabe	15000 h	L_1	The useful life / Vijek uporabe	15000 h
P	The power of plants / Snaga pogona	44 kW	P	The power of plants / Snaga pogona	10 kW
c_e	The price of electricity / Cijena energije po jedinici	0,12 E/kWh	c_e	The price of electricity / Cijena energije po jedinici	0,12 E/kWh
c_w	The price of water / Cijena vode po jedinici	0,5 E/m³	c_w	Price of brass wire / Cijena žice	8 E/kg
m_w	Water flow / Protok vode	0,5 l/s=1800m³/h	φ	Diameter of the wire / Promjer žice	0,2 mm
m_a	The flow of abrasive / Protok abraziva	6 g7s = 21,6 kg/h	v_w	Speed of rewinding wire / Brzina premotanja žice	60 mm/s
c_a	The price of abrasive / Cijena abraziva po jedinici	0,7 E/kg	-	-	-
c_n	Price of mixing jets / Troškovi miješanja mlaznica po jedinici	1200 E	-	-	-
T_n	The useful life mixing of jets / Vijek uporabe miješanja mlaznica	2000 h	-	-	-
c_o	The price of water-jet / Troškovi vodene mlaznice	120 E	-	-	-
T_o	The useful life of water jet / Vijek uporabe vodene mlaznice	75 h	-	-	-
M	Costs of maintenance / Ukupni godišnji troškovi održavanja vodene mlaznice	4000 E/god	M	Costs of maintenance / Ukupni godišnji troškovi	3000 E/god
L_a	Number of working hours / Broj radnih sati	3000 h/god	L_a	Number of working hours / Broj radnih sati	3000 h/god
$C_{awj,h}$	Costs of the machining by abrasive waterjet / Ukupni troškovi obrade abrazivnim vodenim mlazom (AWJ)	38,166 E/h	$C_{awj,h}$	Costs of the wire electrical discharge machining / Ukupni troškovi obrade elektroerozionom obradom s žicom (EDM)	6,867 E/h

In Table 2 is given comparative analysis of the cost wire electrical discharge machining and machining by abrasive waterjet.

The time per unit is the time of one manufacturing operation and can be shown by the relation (6).

$$t_k = t_{pz} + t_p + t_g + t_d, \quad (6)$$

Tables 3 and 4 provide an overview of the components of unit time and production costs per unit concerning abrasive water-jet and wire electrical discharge machining.

7. Conclusion

This paper presents the result of a research conducted under production conditions. Two unconventional methods based on erosion were compared. The main parameter for comparison was machined surface quality depending on traverse speed.

Due to specificity of wire electrical discharge machining, the recommended values of traverse speed can vary within ±5%. During abrasive water-jet machining, values of traverse speed can significantly vary, as well as other machining parameters, without any interference.

Table 3. Overview of the components of unit time and production costs per unit concerning abrasive water-jet machining (AWJM)

Tabela 3. Pregled komponenti komadnog vremena i troškova po jedinici kod obrade abrazivnim vodenim mlazom (AWJ)

z	t_{pz}, s	t_p, s	t_g, s	t_d, s	T_k	t_k	V, E/unit
1	3600	2	92	9	1,03h	1,03h	39,31
10	3600	2	92	9	1,29h	0,129h	4,96
100	3600	2	92	9	3,86h	0,386h	1,53
500	3600	2	92	9	15,31h	0,031h	1,17
1000	3600	2	92	9	29,61h	0,0296h	1,13

Table 4. Overview of the components of unit time and production costs per unit concerning wire electrical discharge machining (WEDM)

Tabela 4. Pregled komponenti komadnog vremena i troškova po jedinici kod elektroerozione obrade sa žicom (EDM)

z	t_{pz}, h	t_p, h	t_g, h	t_d, h	T_k	t_k	V, E/unit
1	0,167	0,05	2,08	0,21	2,507h	2,507h	17,19
10	0,167	0,05	2,08	0,21	23,567h	2,357h	16,16
100	0,167	0,05	2,08	0,21	234,167h	2,342h	16,06
500	0,167	0,05	2,08	0,21	1170,167h	2,34	16,05
1000	0,167	0,05	2,08	0,21	2340,167h	2,34	16,05

Figure 13 shows the analysis of design cost per unit depending on batch size during abrasive water-jet machining (AWJM) and wire electrical discharge machining (WEDM).

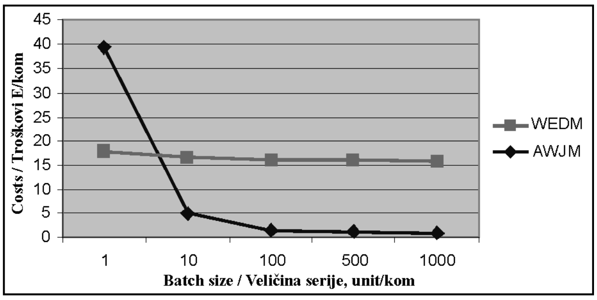


Figure 13. Dependence on manufacturing cost per unit of the batch size for the machining by abrasive waterjet (AWJ) and for the wire electrical discharge machining (WEDM)

Slika 13. Zavisnost troškova obrade po jedinici od veličine serije pri obradi abrazivnim vodenim mlazom (AWJ) i elektroerozionoj obradi sa žicom (EDM)

When measured values of parameters for estimation of machined surface quality (Rasr) are compared, it can be concluded that machined surface quality obtained during abrasive water-jet machining is much higher than the machined surface quality reached during wire electrical discharge machining. This conclusion is even more significant when surface quality during abrasive water-jet machining is reached at traverse speeds which are tremendously higher than traverse speed during wire electrical discharge machining. The value of Rasr parameter increased with the increase in traverse speed during abrasive water-jet machining.

According to all research results, it can be concluded that abrasive water-jet machining is substantially better than wire electrical discharge machining (with Č 4580 wire for steel machining), if the main parameter for estimation of machined surface quality depends on traverse speed.

From economic standpoint, abrasive water-jet machining is accompanied with lower costs for larger batch size, whereas costs of machining of a small number of units exceed the costs of wire electrical discharge machining.

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