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Effect of Various Process Parameters for Wire-Electrical Discharge Machining (WEDM) of D2 Die Steel

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Abstract: Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Wire Electrical discharge machining (WEDM) is a special form of electrical discharge machining (EDM) which is capable to machine hard, refractive materials with great accuracy as compared to conventional machining method. Machine tool industry has made exponential growth in its manufacturing capabilities in last decade but still machine tools are not utilized at their full potential. Die steel alloys are most widely used in die and punch industries for mass production. D2 die steel is widely adopted due to its ability to undergo heat treatment to raise its hardness. High content of chromium increases the corrosion resistance. But still this material is not easily machined with conventional machining method. In present work, mach inability of D2 material has been investigation in terms of material removal rate (MRR) and surface roughness (SR). Experiments were conducted on sprint cut wire EDM made by Electronic Machine Tool ltd India, to investigate the effect of peak current, pulse-on time, pulse off- time, servo voltage, dielectric flow rate, wire feed rate on the mach inability of D2 die steel. Experimental results show that the cutting speed and surface roughness both increase with increase in peak current. Cutting speed also increases in different proportions with increase in pulse duration. There is sharply decrease in cutting speed with increase in pulse-off time but we get the fine surface finish with increase in pulse-off time. The cutting speed first increase with increase in servo voltage and then decrease as there is more discharge energy b/w the machining zone and same result in case of surface roughness. Effect of electrode material on cutting speed and surface roughness is noticeable. Based on these results we found that pulse-on time, Pulse-off time, peak current and electrode material are the most significant factors affecting both machining characteristics i.e. cutting speed and surface roughness. Generally we can use wire feed rate 3 or 4m/min for better performance.

Keywords: D-2 Die Steel, Wire EDM, Machining parameters, Cutting Speed, Surface Roughness.

1. INTRODUCTION

Electric discharge wire cutting, more commonly known as wire electrical discharge machining (WEDM) is a spark erosion process used to produce complex two or three dimensional shapes through electrically conductive work pieces by using wire electrode. The spark will be generated b/w the work-piece and a wire electrode flushed with or immersed in a dielectric fluid. WEDM has been an important non- traditional machining process and regarded as a reliable and flexible machining method due to its capability of machining any material with electrical conductivity more than .01µs/cm. The material removal mechanism of WEDM is very similar to the conventional EDM process involving the erosion effect produced by the electrical discharges spark. The material erosion mechanism primarily make use of electrical energy and turns it in to thermal energy through a series of discrete electrical discharges occurring b/w the tool electrode and work piece electrode separated by a stream of dielectric fluid (kerosene, distilled water) which is continuously feed to the machining zone. The thermal energy generates a channel of plasma b/w the cathode (tool electrode) and anode (work piece electrode) at a temp. in the range of 8000^{o}C to 12000^{o}C. When the pulsating direct current supply is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten material from the pole surface in the form of microscopic debris. This process leaves tiny pits and craters on the work and electrode surface. The size of such crater depends on the energy content of the spark on the basis of this pulse energy used.

According to intensity of pulse energy we classify the WEDM in to two types:-

1) **Roughing WEDM**
2) **Finishing WEDM**

D2 die steel is widely used in die and punch manufacturing due to its heat treatability to acquire the good combination of hardness and toughness. The present work material was in the form of rectangular block of 24mm thickness. It was heat treated before machining to refine the grain structure and to raise its hardness up to 56HRC. D2 steel contains nearly 1.2% C, 12% Cr, 1% V, 0.6% Si, 0.6%Mn and rest is Fe.

Experiments were conducted over wide range of the machining parameters during rough cutting operation in wire EDM. MRR and SR were two performance measures. Out of eight machining parameters, effect of wire-offset is not evaluated on performance measure. Wire-offset is the distance between wire periphery and work piece surface. In rough cutting operation, when wire moves through the work material, wire offset affects only dimensional tolerances but it does not affect MRR and SR. In present case, all experiments were performed with zero wire offset value and fixed servo feed 2080.

2. EXPERIMENTAL SETUP

In this study, experiments were performed on 5-axis sprint cut (ELPLUS) wire electrical discharge machine manufactured by Electronica Machine Tool Ltd India, to examine the effect of machining parameters namely peak current (Ip), pulse-on time(Ton), pulse-off time (Toff), wire feed rate(WF), servo voltage(SV) and dielectric flow rate(DFR) on machining performance of D2 die steel. Zinc coated brass wire and plane brass wire of diameter .25mm was used as an electrode because of its good capability to sustain high discharge energy. Distilled water was used as a dielectric fluid. Machine capability range of selected variables and fixed parameters are listed in table 1.

Table-1: Different parameters used and machine specification

Fixed parameters	Value	Variable parameters range in WEDM	
Wire Type	Plane brass wire and zinc coated wire	Peak current	010-230 Ampere
Work material	D-2 die steel	Pulse-on Time	100-131 µs
Work-piece thickness	25mm	Pulse-off Time	14-63 µs
Work-piece hardness	56 HRC	Servo Voltage	10-90V
Wire tension	8N	Wire feed rate	1-15m/min.
Servo feed setting	2080	Dielectric flow rate(upper nozzle)	0-10L/min.
Dielectric flow rate	7 L/min.		
Wire off-set	0mm		

A D2 die steel plate of size 125×100×25mm is taken as a work-piece material. Composition of D2 die steel is (C 1.3%, Al .54%, V 1.3%, Cr 13.13% and Fe 83.03%). All the six faces of tool steel plate are grinded to remove the burrs & rusts so that wire moves smoothly throughout the work-piece. A variety of tool steels available for manufacturing metal forming tools, it is often possible to choose a tool steel with a favorable combination of properties for particular applications. By comparing the levels of metallurgical properties offered by different steels, tool users can determine which tool steels are best suited for fixing or resisting performance problems, or for enhancing tool performance. Tool steels can be categorized and compared by those properties which have a direct influence on tool performance: hardness, toughness (impact resistance), wear resistance.

3. METHODOLOGY

In this present work single variable at a time approach concept is used to find out the effect of input parameters on the machining characteristics like cutting speed or MRR, surface roughness etc. In each experiment one input variable was varied while keeping all other input variables at some fixed value. A series of experiments were conducted to study the effect of various machining parameters on WEDM process. Studies have been undertaken to investigate the effects of selected parameters viz., discharge current, pulse on time, pulse-off time, wire feed, wire tension on cutting speed & surface roughness. Single variable at a time approach concept is used to find out the effect of these input parameters on material removal rate and surface roughness. Experiments were carried out on D2 die steel material as a work-piece electrode & brass copper as a tool electrode. Distilled water has been used as a dielectric fluid throughout the tests.

4. EFFECT OF MACHINING VARIABLES ON CUTTING SPEED & SURFACE ROUGHNESS

In this section, the influence of machining variables namely peak current (Ip), pulse-on time (Ton), pulse-off time (Toff), servo voltage (SV), wire electrode material and wire feed rate (WF) on cutting speed (or material removal rate) and surface roughness (SR) are discussed. Zinc coated brass wire was used to produce vertical cuts in the carbide block. Experiments were carried out at the constant value of wire tension 8N and lower dielectric flow rate of 6 litres per minute (LM-1). Wire speed was kept at 8m/min. to evaluate the effect of peak current, pulse-on time, pulse-off time, servo voltage and dielectric flow rate on cutting speed (CS). CS was measured in mm/min which was displayed on computer screen of the machine control unit (MCU).

Effect of peak current

The effect of peak current on cutting speed and surface roughness of D2 die steel with wire EDM is shown in figs.1-2, under different conditions of pulse-on time (105µs, 110µs, 115µs). The other fixed parameters were pulse-off time 30µs, servo voltage 30V, wire feed 7m/min. Plane brass wire of 0.25mm diameter was taken as tool electrode. It is clear from figure that at low pulse duration (110µs) the cutting speed is low and nearly constant. This is because of low discharge energy is produced b/w the working gap due to insufficient heating of work-piece and low pulse duration. At high pulse duration (110µs, 115µs) there is rise in cutting speed as we increase the peak current. this is due to sufficient availability of discharge energy and heating of the work-piece material. The small increase in cutting speed at high value of peak current and pulse duration is related to inferior discharge due to insufficient cooling of the work material.

Table-2: Effect of peak current on cutting speed

	Ton=105	110	115
Ip	CS	CS	CS
60	0.58	0.98	1.23
70	0.6	1.01	1.235
80	0.615	1.09	1.34
90	.64	1.12	1.59
100	0.657	1.17	1.79
120	0.645	1.25	1.86

The optimal material removal rate for D2 die steel took place at a peak current intensity of 85A as we can see from the figure. The cutting speed remains constant up to value of peak current 70A with different value of pulse duration. This is due to insufficient heating of the work-piece material. The effect of peak current on surface roughness is shown in figure 2.The surface roughness of D2 die steel increase with increase in peak current and pulse duration.

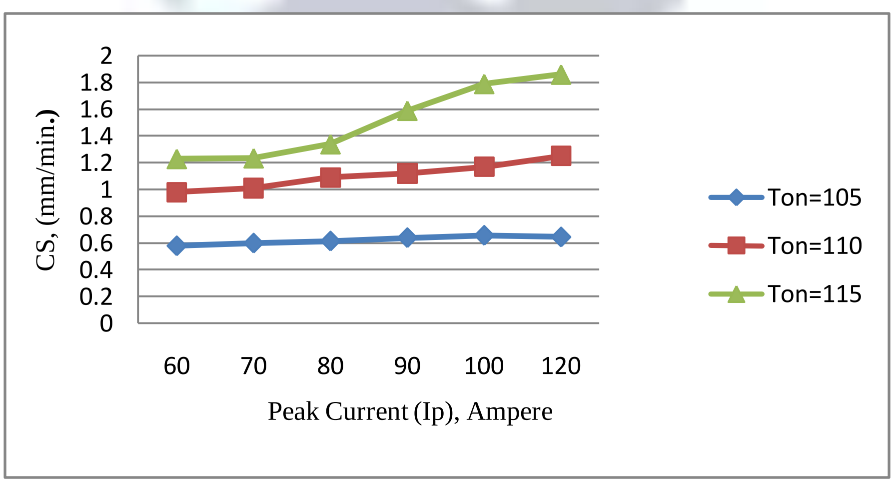

Fig- 1: Effect of peak current on cutting speed

Table-3: Effect of peak surface roughness current

	Ton=105	Ton=110
Ip	SR	SR
60	1.11	1.32
80	1.09	1.64
100	1.2	1.95

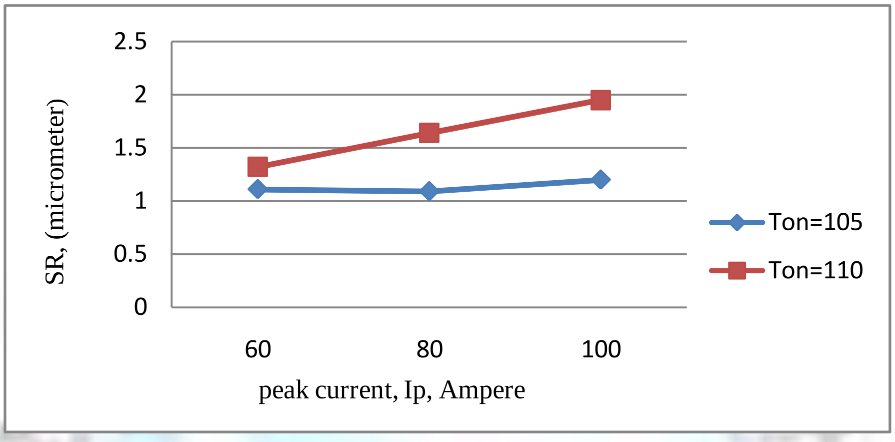

Fig- 2: Effect of peak current on surface roughness

The surface roughness is function of two parameters, peak current and pulse-on time, both of which are function of power supply. A rough surface is produced at high peak current and/or pulse-on time. The reverse is also true. From fig. 2 we can also see that at low value of peak current the value of surface roughness is also low. Thus a finer surface texture will be produced at low value of peak current and/or pulse duration and vice versa.

This is due to because pulse energy per discharge is can be expressed as follows:

$$E=\int_{o}^{to} u(t)i(t)dt$$

Where to is pulse duration, u(t) is the discharge duration, i(t) is the discharge current and E is the pulse energy per discharge. Since the discharge voltage u(t) stays constant during the discharge pulse duration and discharge current. Thus from above formula of discharge energy we can say at low value of discharge current and/or pulse duration discharge energy will be low and at high value discharge energy will be high. But higher discharge energy will worsen the surface roughness because of increase in diameter and depth of the discharge craters which is in agreement with work carried by Fuzhu Han. et.al (2007). So in order to control the fine surface we must control the pulse energy per discharge.

Effect of pulse-on time

The effect of pulse-on time (pulse duration) on cutting speed and surface roughness is shown in Figure 3-4., under different value of peak current Ip (60A, 100A, 120A) at a pulse interval (Toff) of 30µs, SV 30V, wire feed 7m/min, a brass wire as a tool electrode and D2 die steel as a work-piece material.

Figure 3 shows the results of cutting speed of D2 die steel material during its machining. From result we found that cutting speed increase with increase in pulse duration at all value of peak current. Thus cutting speed is a function of pulse duration but at low value of peak current(Ip=60) the cutting speed is low due to the insufficient heating of the material and also after pulse duration(Ton=110) the rise in cutting speed is low because of insufficient clearing of debris from the gap due to insufficient pulse interval.

Table-4: Effect of pulse-on time on cutting speed

	Ip=60	Ip-100	Ip=120
Ton	CS	CS	CS
105	0.58	0.657	0.645
110	0.98	1.17	1.25
115	1.23	1.79	1.86
120	1.43	2.16	2.3

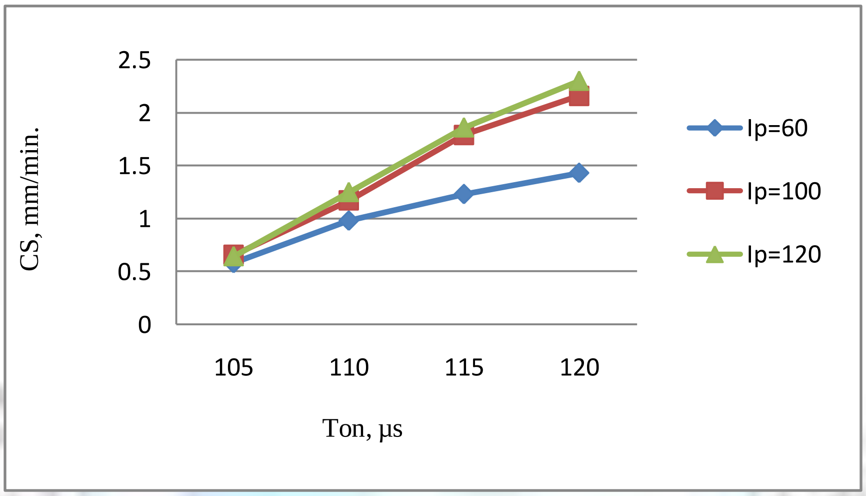

Fig- 3: Effect of pulse-on time on cutting speed

Figure 4, shows the effect of pulse-on time on surface roughness for different settings of Ip(60A, 100A, 120A). The other parameters were kept constant. Experimental results show that surface roughness increase with increase in pulse duration at different setting of peak current but we found that surface roughness at low value of pulse duration and high value of peak current is less than the at high value of pulse duration and low value of peak current. This is due to because at low pulse duration materials remove mainly by gasifying and forms craters with ejecting morphology due to high value of peak current and heat flux in the ionized channel, which causes the temperature of the work-piece to be raised or to be easily exceed the boiling point. On the other hand a long pulse duration removes material mainly by melting and forms craters with melting morphology due to low value of peak current and heat flux in the ionized channel, which prevents the temperature of the work-piece from reaching a high value. Which is in agreement with the work carried by Fuzhu Han, et. Al(2007).Minimum surface roughness of D2 die steel with present machine tool occur at the Ton 105µs and Ip 120A.

Table-5: Effect of pulse-on time on surface roughness

	Ip=60	Ip-100	Ip=120
Ton	SR	SR	SR
105	1.11	1.2	1.06
110	1.32	1.95	1.43
115	2.13	2.75	2.9
120	2.8	3.185	3.27

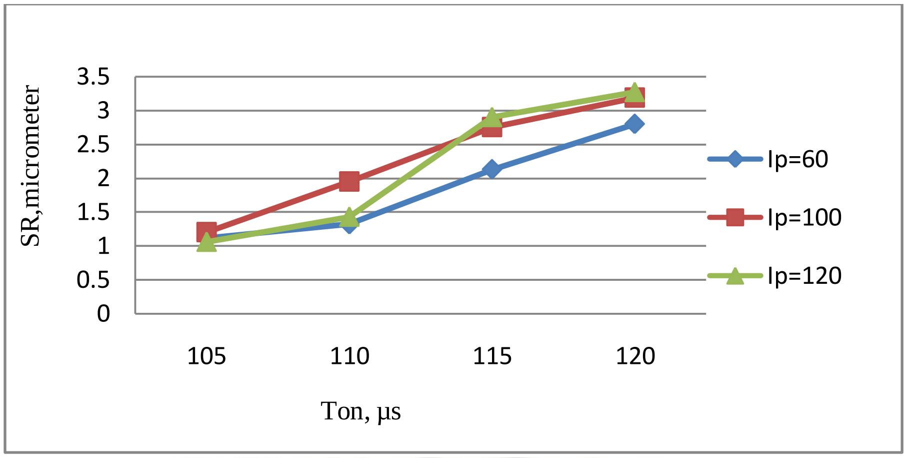

Fig- 4: Effect of pulse-on time on cutting speed

Table-5: Effect of pulse-off time on cutting speed

	Ton=105	Ton=110	Ton=115
Toff	CS	CS	CS
30	0.657	1.17	1.79
40	0.46	0.78	1.32
50	0.237	0.48	0.66

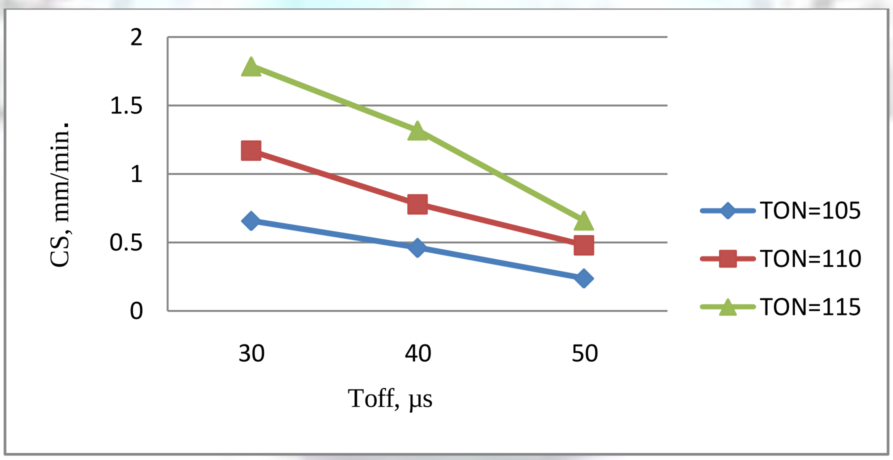

Fig- 5: Effect of pulse-off time on cutting speed

The effect of pulse-off time on cutting speed is shown in figure 4. As shown in fig. the cutting speed decreases when pulse-off time is increased. This is due to as with long pulse-off time the dielectric fluid produces the cooling effect on wire electrode and work material and hence decreases the cutting speed.

Table-6: Effect of pulse-off time on surface roughness

	Ton=105	Ton=110	Ton=115
Toff	SR	SR	SR
30	1.2	1.95	2.75
40	1.19	1.27	2.58
50	1.19	1.86	1.69

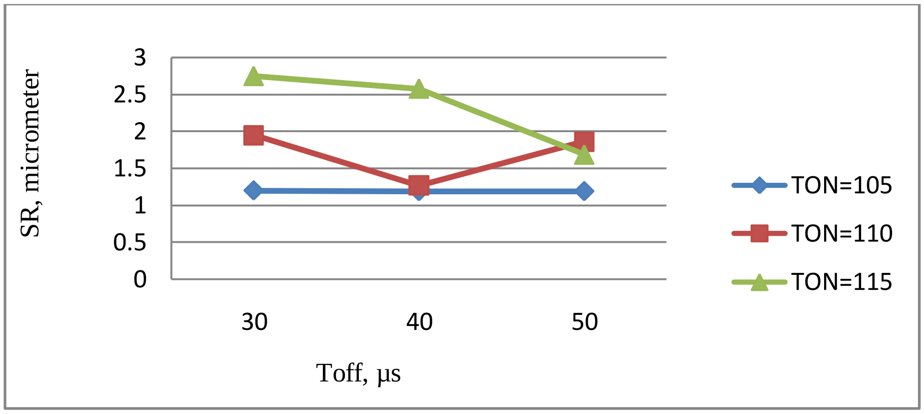

Fig- 6: Effect of pulse-off time on surface roughness

Figure 6 shows the effect of pulse-off time on surface roughness. The surface roughness changed little even though the pulse-off time changed corresponding to a small value of pulse-on time. Mainly surface roughness improves with increase in pulse-off time. The surface roughness is high at low value of pulse-off time, this is due to because with a too short pulse-off time there is not enough time to clear the melted small particles from the gap b/w the tool electrode and work-piece and also not enough time for de-ionization of the dielectric: arcing occur and the surface becomes rougher. As we can see from the fig. surface roughness decrease up to pulse-off time 40µs and then increase with increase in pulse-off time. This is because more energy is required to establish the plasma channel and there-for there is higher electrode wear and higher surface toughness. We obtain the fine surface at pulse-off time 40µs with this machine taking D2 die steel as a work-piece material.

Effect of servo voltage

The effect of servo voltage on cutting speed and surface roughness is depicted in Figure 7-8 with different pulse duration (Ton 110µs and 115µs) keeping other variables fixed at Toff 30µs, Ip 100A and WF 7 m/min.

Table-7: Effect of servo voltage on cutting speed

	Ton=110	Ton=115
SV	CS	CS
20	0.89	1.81
30	1.17	1.79
40	1.08	1.63
50	0.9	1.4
60	0.8	1.11

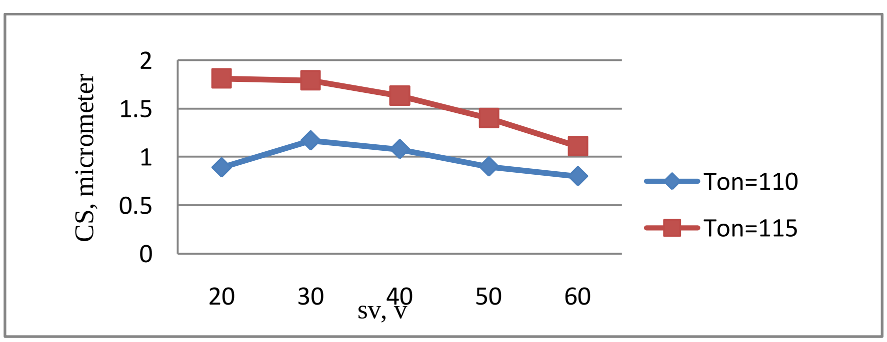

Fig- 7: Effect of servo voltage on cutting speed

Experimental results show that the cutting speed increase with increase in servo voltage and then it starts to decrease. This is due to increase in servo voltage result in higher discharge energy per spark because of large ionization of dielectric b/w working gap. Consequently, the cutting speed (MRR) increases. However, a too high voltage result in high discharge energy per spark which causes unfavorable break down of dielectric and large amount of debris b/w the working gap which unable the material removal rate increases. The cutting speed is highest at SV 30.

Effect of servo voltage on surface roughness is depicted in figure 7. Experimental results show that surface roughness at low value of pulse duration with increase in servo voltage first increases up to 30V and then decrease with increase in servo voltage. At high value of pulse duration the surface roughness continuously decrease with increase in servo voltage. This is due to because at low pulse duration the discharge energy is low so melted particles cannot flow out of the machining zone and impinge on the work-piece material and surface roughness increase but with increase in more servo voltage more energy is produced which leads to uniform melting and melted particles flushed out b/w the working gap.

Table-8: Effect of servo voltage on surface roughness.

	Ton=110	Ton=115
SV	SR	SR
20	1.55	3.16
30	1.95	2.75
40	1.68	2.53
50	1.54	2.58
60	1.5	2.55

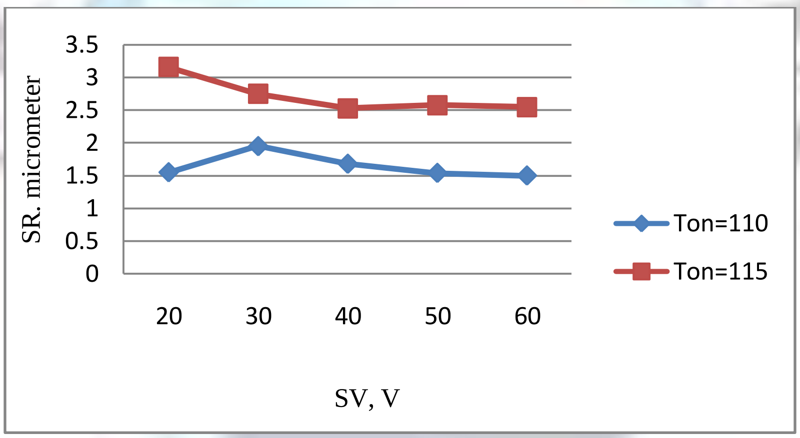

Fig- 7: Effect of servo voltage on surface roughness

Effect of wire feed rate

The effect of wire feed rate on cutting speed and surface roughness is shown in Figure 8-9 With different pulse duration (Ton 115µs and Ton 125µs) keeping other variables fixed at Toff 30µs, Ip 100A and SV 30V.

Table-9: Effect of wire feed rate on cutting speed

	Ton=115	Ton=125
WF	CS	CS
5	1.75	2.47
7	1.8	2.65
10	1.78	2.55

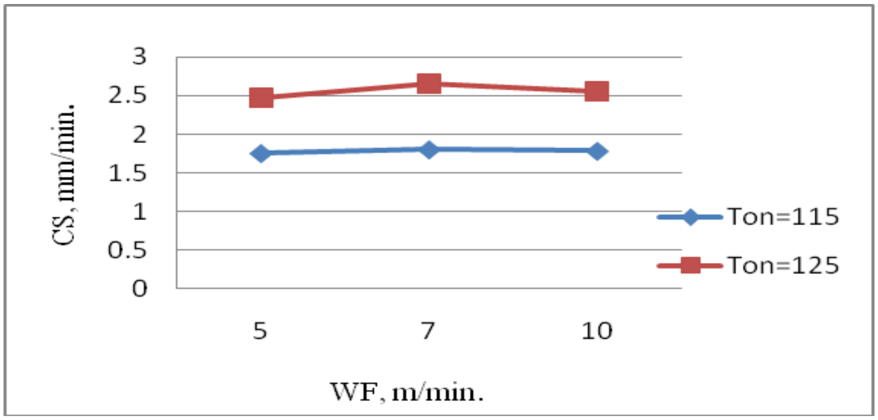

Fig- 8: Effect of wire feed rate on cutting speed

From figure 8 we found that there is very small increase in cutting speed or nearly constant cutting speed with increase in wire feed rate. The maximum material removal rate is obtained at wire feed rate of 7m/min. this is in agreement with Ahmet Hascalk and Ulas Caydas (2004). Cutting speed increases with increase in wire feed rate because there is less dissipation to the surrounding and hence more heat generated at spark gap, leading to higher material removal rate. For further increase in feed rate the cutting speed decrease due to the un-flushed debris b/w the working gap or unwanted melted particles b/w the working gap which form an electrically conductive path b/w the tool electrode and work-piece, causing unwanted spark b/w the tool electrode and work-piece. Thus only a portion of energy is used in work material removal which reduces the cutting speed. This is in agreement with work carried out by Kodalagara Puttanarasaiah Somashekhar et. al (2010).

Table-10: Effect of wire feed rate on surface roughness

	Ton=115	Ton=125
WF	SR	SR
5	3.26	3.21
7	3.06	3.19
10	2.26	3.1

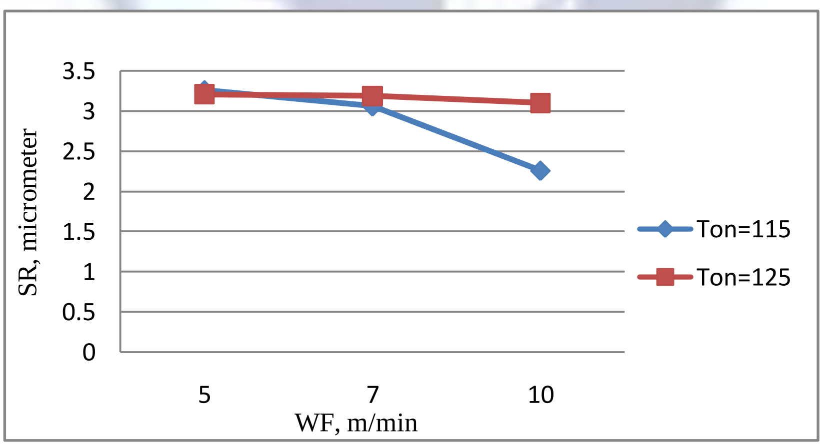

Fig- 9: Effect of wire feed rate on surface roughness

Figure 9 shows that surface roughness decreases with increase in wire feed at different value of pulse on time. As we know with increase in wire feed rate area of work-piece electrode is small in comparison with the wire electrode and most heat is generated on the work-piece electrode. So that uniform melting of the work-piece and vaporized or melted material flush away by the dielectric fluid sufficiently. As a result finish surface is produced by the machining which is in agreement with the work carried out by the C.A.Huang, et. Al (2003).

Effect of wire electrode material

The effect of wire electrode material on cutting speed and surface roughness is shown in Figure 10-11 with different pulse duration (Ton 105μs, 110μs, 115μs, 120μs and Ton 125μs) keeping other variables fixed at Toff 30μs, Ip 100A and SV 30V and WF 4m/min.

Table-11: Effect of electrode material on cutting speed

	zinc coated	brass wire
Ton	CS	CS
105	1.02	0.69
110	1.75	0.96
115	2.34	1.81
120	2.79	1.9
125	2.94	2.63

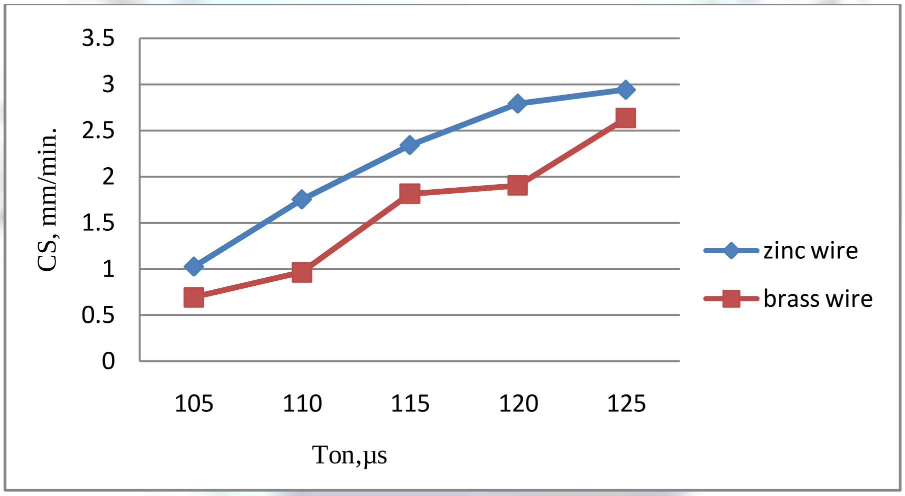

Fig- 10: Effect of electrode material on cutting speed

Effect of electrode materials on cutting speed is shown in figure 10. High cutting speed is obtained with zinc coated electrode material. This is due to zinc coated wire is composed of a copper or brass core coated with zinc layer of suitable thickness. This outer coated layer of electrode material is characterized by a lower melting temperature in relation to core material. When a pulse is applied the wire coating is overheated and then evaporated. Therefore a heat sink effect on the wire and thus a cooling of the core material is obtained. This heat sink phenomenon results in the improvement of the efficiency of the WEDM process by reducing wire temperature and therefore allowing a more intense thermal flow, leading to an increase of the cutting speed. Also due to the coating evaporation the gap size increases leading to better dielectric flushing and debris removal. That's why we obtain high cutting speed with zinc coated wire electrode in comparison to brass wire.

Effect of electrode material on surface roughness is shown in figure 11. The surface is most affected by the amount of discharge energy and surface roughness depends on the size of crater spark crater. Large discharge energy will cause violent sparks resulting in a deeper erosion crater on the surface. Accompanying the cooling process after the spilling of molten material residues will remain at periphery of the crater to form a rough surface. Furthermore grater discharge energy will produce a large crater, causing a large surface roughness value on the work-piece.

Table-12: Effect of electrode material on surface roughness

	zinc coated	brass wire
Ton	SR	SR
105	1.26	1.17
110	3.2	2.27
115	3.21	2.89
120	2.015	1.36
125	3.4	3.32

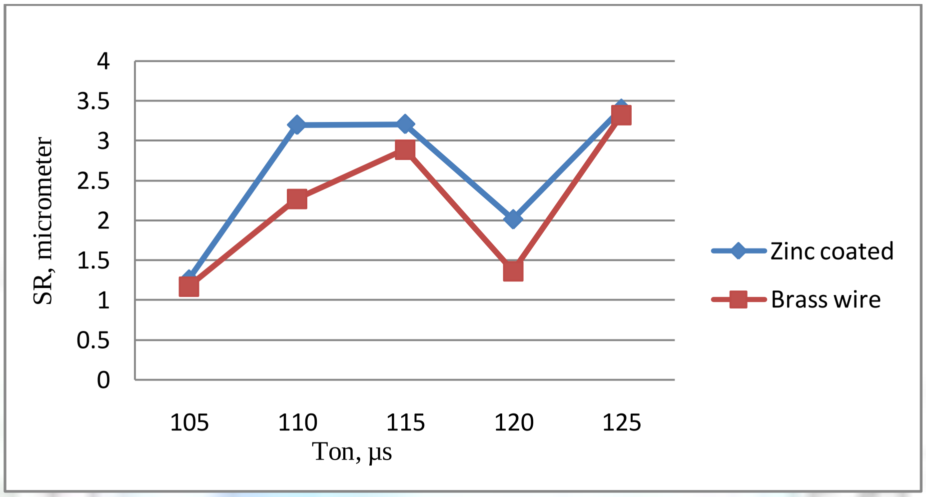

Fig- 11: Effect of electrode material on surface roughness

CONCLUSIONS

In this study, the machinability of die steel (D2) material with wire EDM has been investigated in terms of cutting speed and surface roughness. The effect of process variables i.e. effect of peak current, pulse-on time, pulse-off time, servo voltage, wire feed rate and electrode material were investigated by varying single variable at a time. Based on experimental results following conclusion are made:

1. Cutting speed or material removal rate and surface roughness both increase with increase in peak current and pulse-on time and vice-versa.
2. Cutting speed or material removal rate and surface roughness both decrease with increase in pulse-off time and servo voltage. Thus fine surface get as we increase the value of both these variables.
3. Effect of wire feed rate on cutting speed surface roughness is negligible. Hence machine can be operated efficiently at low value of wire feed rate. Generally 3 to 4m/min. is advised in present work.
4. Use of zinc coated wire electrode increase the cutting speed and surface roughness as compared to plane bras wire this is due to the high amount of discharge energy available across the electrodes.

From the experimental results we found the ranges of process variables b/w which machine out-put characteristics (cutting speed and surface roughness) varies significantly and obtained the optimal machining performance b/w these ranges. The obtained process variable ranges are shown in the following table:

Table-12: Process variable ranges

In-put variable	From	To
Ip(ampere)	80	130
Ton(μs)	105	120
Toff(μs)	30	45
SV(V)	20	50
WF(m/min.)	3	4

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