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INVESTIGATION OF MACHINING CHARACTERISTICS OF TUNGSTEN CARBIDE BY WIRE CUT EDM PROCESS

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ABSTRACT

The investigation of machining characteristics is one the most important aspects to take into consideration in the majority of manufacturing processes and particularly in processes related to Wire cut Electrical Discharge Machining (WEDM) being widely used in die and Tool making industries, aerospace, aeronautics and nuclear industries. Hence it's wide use and has high hardness requires unconventional machining such as WEDM, the investigation of machining characteristics of Tungsten carbide will provide a more economic and efficient method in it. The work material Tungsten carbide was WEDM machined with Brass and Molybdenum wires by varying process parameters. The machining parameters that we are going to investigation are peak current, Pulse on time and pulse off time and analyses the output parameters such as material removal rate (MRR) and surface roughness (Ra), with the help of ANNOVA and Taguchi methods of analysis to obtain the best operating parameter. Investigation indicates that the material removal rate is higher with Molybdenum Wire than Brass wire.

Keywords: Wirecut Electrical Discharge machining, Tungsten Carbide, Metal Removal Rate, Surface roughness, Analysis of variance, Taguchi methods.

INTRODUCTION

Electrical discharge machining (EDM) is a non-conventional machining concept which has been widely used to produce dies, moulds and metalworking industries. This machining method is commonly used for very hard metals that would be impossible to machine with conventional machine. It has been widely used, especially for cutting complicated contours or delicate cavities that also would be tough to produce with conventional machining methods. However, one critical limitation is that EDM is only works with electrically conductive materials. Metal that can be machined by using EDM include nickel-based alloy (such as aerospace material), very hard tool steels etc.

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the workpiece and the wire, eliminating the mechanical stresses during machining.

After computer numerical control (CNC) system was initiated into WEDM that brought about a major evolution of the machining process. As a result, the broad capabilities of the WEDM process were extensively exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined. The common applications of WEDM include the fabrication of the stamping and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts, and grinding wheel form tools.

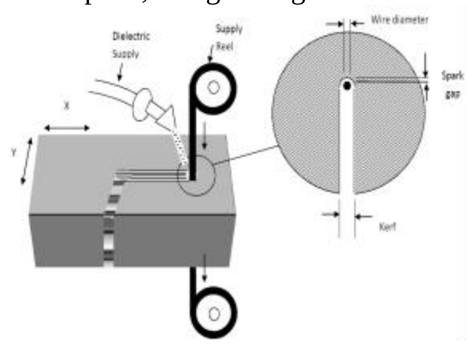

Fig 1-Wire cut EDM

The melting temperature of the parts to be machined is an important factor for this process rather than strength or hardness. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode, and turns it into thermal energy at a temperature in the range of 8000–12,000°C or as high as 20,000°C initializing a substantial amount of heating and melting of material on the surface of each pole. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channel breaks

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down. Hence the present article objective is to study experimental investigation and machining characteristic of WEDM on tungsten carbide and to analyse the effect of input parameter of WEDM in tungsten carbide material.

WIRE ELECTRODES

Wires used in this machine as the cutting tool. The wire is usually made of brass, copper, or tungsten; zinc or brass coated and multi-coated wires are also used. Pure copper or brass is extensively used as an electrode material. It is used when fine finishes are required in the work piece. It exhibits a very small wear ratio. A major problem with copper is its poor machinability.

The properties required for the wire electrode are:

1. Electrical properties
2. Geometrical properties
3. Physical properties
4. Mechanical properties

Electrical discharge performance is desired for steady and elevated energy discharge for high-speed cutting. The electrical properties are articulated by its electrical resistance. Energy losses are minimized by using two current contacts and selecting high-conductivity electrode materials, such as copper, brass, aluminum and its alloys, with optimized settings. Conductivity determines how readily the energy is transferred from power feed to the actual point of cutting. Improving the surface area of the wire will allow faster cutting. The wires diameter is typically about 0.3mm for roughing cut and 0.20mm for finishing cuts. The wire should have sufficient tensile strength and fracture toughness. As well as high electrical conductivity and capacity to flush away the debris produced during cutting.

DIELECTRIC FLUID

Dielectric fluid is a nonconductive liquid that fills between the work piece and electrode and act as an electrical insulator until needed space and voltage reaches. At that point dielectric fluid ionizes, becoming an electrical conductor and cause the current or spark to flow to the work piece.

The main functions of the dielectric fluid are:

- To flush the eroded particles produced during machining, from the discharge gap and remove the particles from the oil to pass through a filter system.
- To provide insulation for the gap between the electrode and the work piece.
- To cool the section that was heated by the discharge machining.

SELECTION OF MATERIAL

Tungsten carbide (chemical formula: WC) is an inorganic chemical compound (specifically, a carbide) containing equal parts of tungsten and carbon atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, cutting tools, abrasives, armor-piercing rounds, other tools and instruments. Tungsten carbide is approximately two times stiffer than steel, and much denser than steel or tungsten carbide. It exhibits the highest operating temperature of all metals about 3173 K as well as the melting temperature is about 3693 K.

Machining tungsten carbide using conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. So Tungsten carbide is classified as difficult-to-machine materials. Tungsten carbide are used in many different industries such as automobile, aerospace, Cutting Tools, Ammunition, Nuclear and sports industry.

Table.1.Properties selected material

Density	15.63 g/cm3
Melting point	270ºC
Coefficient of expansion	5.8 $\mu m \cdot m^{-1} \cdot K^{-1}$
Hardness (HV5)	116 GPa
Modulus of elasticity	550 GPa
Ultimate Strength (MPa)	344.8
Shear Modulus (GPa)	270
Bulk modulus (GPa)	439

Table.2.Chemical composition of selected material

Wc	Co	rs
89.50	10.00	0.50

SELECTION OF WIRE ELECTRODE

Here we choose two types of electrode and compare so as to know which is enhance the performance and which doesn't. Brass wires are the combination of copper and zinc, alloyed in the range 63%–65% copper and 35%–37% zinc. Machining speed increases with the presence of zinc in the EDM wire electrode owing to stable discharge during machining. The zinc in the brass wire actually boils off, or vaporizes, which helps cool the wire and delivers more usable energy to the work zone. The addition of zinc in the wire provides a higher tensile strength, lower melting point, higher vapor pressure rating and improved flushability, but its conductivity is significantly reduced. Machining speed can be further enhanced with the addition of more zinc (more than 40%) to the wire, but in that case the drawing process to form a wire becomes difficult because of the presence of a brittle phase in the alloy.

Molybdenum wire electrode. For smaller diameters (0.004 in and under), molybdenum or tungsten wire electrodes are used because of their high tensile strength and load-carrying capability. The tensile strength of the pure molybdenum is approximately 1.6 times and tungsten is 3 times that of a plain brass wire electrode. Their use is limited because of low electrical conductivity and flushing. Tungsten and molybdenum wires also have poor discharge, low tensile strength at high temperature, which leads to poor surface finish, and wire failure.

This drawback was removed by using the molybdenum alloy containing one or more of the oxides of Al, Si and K, and tungsten alloyed with rare earth elements like Y, La, Ce, and their oxides. The tensile strength and strains in the wire of molybdenum alloy was improved as the fine particles of the oxides are uniformly dispersed in the molybdenum, so that the recrystallization temperature of the molybdenum alloy becomes higher and accordingly the tensile strength of the molybdenum alloy at high temperatures is improved. The molybdenum wire electrode is also abrasive to power feed and wire guides, moreover they are very expensive. The diameter of the molybdenum and tungsten cutting wires can be reduced for more precise processing.

EXERIMENT USING TAGUCHI METHOD

Number of experiments was determined using the Taguchi method. The Taguchi method is a powerful and efficient design of experiment technique, which can improves process performance with a minimum number of experiments. It reduces, rework costs, manufacturing and cycle time costs in processes. The Taguchi design is to find optimal values of the objective function in manufacturing processes. Compared to traditional experimental designs, the Taguchi method makes use of a special design of orthogonal array to examine the quality characteristics through a minimal number of experiments. The experimental results are then transformed into S/N ratios to evaluate the performance characteristics. Therefore, the Taguchi method concentrates on the effects of variations on quality characteristics, rather than on the averages. That is, the Taguchi method makes the process performance insensitive to the variations of uncontrollable noise factors. The optimum parameter conditions are then determined by performing the parameter design.

The general steps involved in the Taguchi Method are as follows:

1. Define the process objective, or more specifically, a target value for a performance measure of the process. The target of a process may also be a minimum or maximum.
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.
3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment.
4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5. Complete data analysis to determine the effect of the different parameters on the performance measure.
6. The parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined.
7. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter.
8. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less value can be tested or the values tested can be closer together.

EXPERIMENTAL WORK

The EZEECUT PLUS Wire cut EDM was used to carry out the experiments. The Ti6Al4V has been applied as work piece material for the present experiments. The shape was machined by WEDM with 39mmx10 mmx5 mm size. Two types of wire electrode were used namely Brass wire and Molybdenum wire. De-ionized water was selected as the dielectric for experiments, as that is the standard for Wire EDM.

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Table.3.Orthogonal array of Taguchi method

EXPERIMENTS	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table.4.Parameters and its range

PARAMETERS	RANGE OF PARAMETERS
Current	1-3 A
Pulse ON	32-36 µs
Pulse OFF	6-8 µs

Table.5.Factors and levels

Factors	Level-1	Level-2	Level-3	Units
I_p	1	2	3	A
T_{on}	32	34	36	µs
T_{off}	6	7	8	µs

Table.6.List of experiment conducted

EXPERIMENT NO	Current(A)	Pulse ON (µs)	Pulse OFF (µs)
1	1	32	6
2	1	34	7
3	1	36	8
4	2	32	7
5	2	34	8
6	2	36	6
7	3	32	8
8	3	34	6
9	3	36	7

RESULT

The experimental results are collected for material removal rate and surface roughness. 9 experiments were conducted using Taguchi (L9) experimental design methodology and there are two replicates for each experiment to obtain S/N values. In the present study all the designs, plots and analysis have been carried out using Minitab statistical software. Larger material removal rate and lower amount of surface roughness show the high productivity of Wire EDM. Therefore, large the better and small the better are applied to calculate the S/N ratio of cutting speed and surface roughness respectively.

1. Larger the Better: $(S/N)_{HB} = -10\text{Log}\,(MSD_{HB})$

$$\text{Where: } MSD_{HB} = 1/R\sum_{i=1}^{R}\left(\frac{1}{yi^2}\right)$$

2. Smaller the Better: $(S/N)_{LB} = -10\text{Log}\,(MSD_{LB})$

$$\text{Where: } MSD_{LB} = MSD_{LB} = 1/R\sum_{i=1}^{R}\left(yi^2\right)$$

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Table.7.MRR Calculation table

Experiment No	MRR(mm^3/min) for brass	MRR(mm^3/min) for molybdenum	S/N Ratio for brass	S/N Ratio for molybdenum
1	0.78270	1.4899	-2.1281	3.4631
2	0.74020	1.4627	-2.6130	3.3031
3	0.66551	1.2934	-3.5370	2.2347
4	1.57509	2.7819	3.9456	8.8868
5	1.24279	2.6133	1.8873	8.3438
6	1.73898	3.2002	4.8055	10.1035
7	1.85608	3.5379	5.3716	10.9749
8	2.46404	2.8755	7.8328	9.1743
9	2.07505	3.3096	6.34036	10.3955

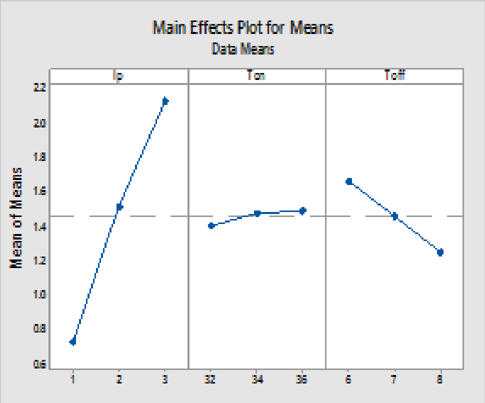

Fig.2.Effects of parameters plot on MRR for mean of brass wire

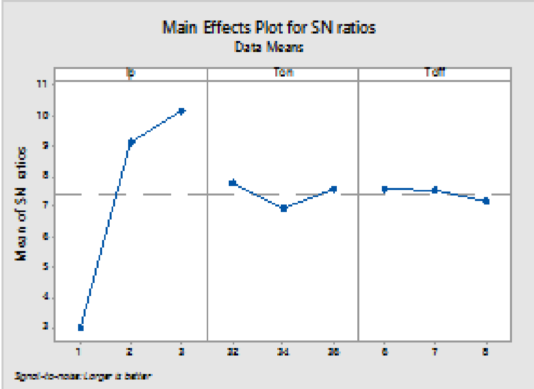

Fig.3.Effects of parameters plot on MRR for SN-ratio of brass wire

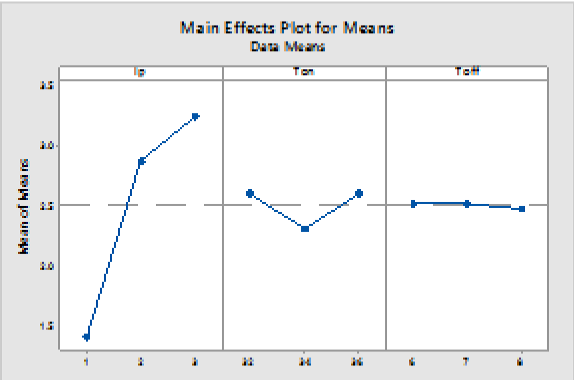

Fig.4.Effects of parameters plot on MRR for mean of Molybdenum wire

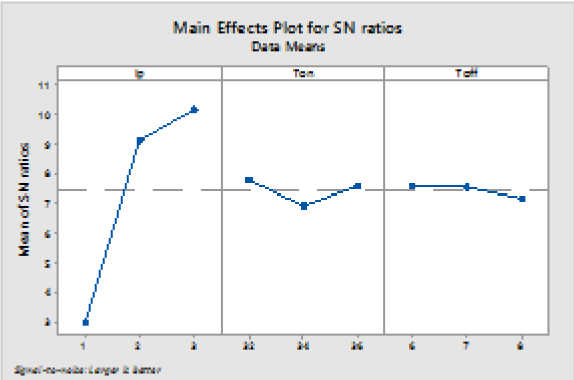

Fig.5.Effects of parameters plot on MRR for SN-ratio of Molybdenum wire

Table.8.Surface roughness calculation table

Experiment No	R_a (μm) for Brass	S/N ratio for Brass	R_a (μm) for molybdenum	S/N ratio for Molybdenum
1	1.156	-1.2592	1.1421	-1.1541
2	1.091	-0.7565	1.0566	-0.4782
3	1.185	-1.4744	1.121	-0.9921
4	1.506	-3.5565	1.2745	-2.1068
5	1.627	-4.2278	1.4837	-3.4269
6	1.822	-5.2110	1.7373	-4.7975
7	2.104	-6.4609	2.0679	-6.3106
8	2.1335	-6.5819	2.2634	-7.0952
9	2.648	-8.4584	2.3261	-7.3326

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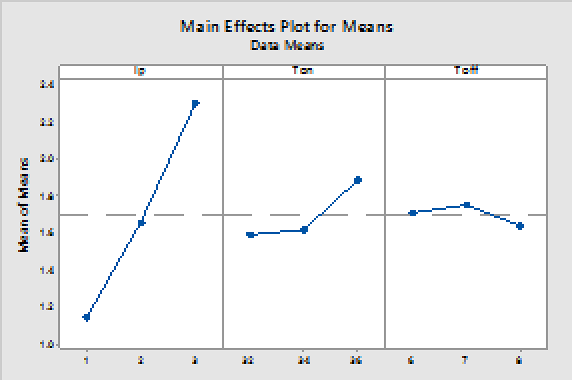

Fig.6.Effects of parameters plot on Ra for mean of brass wire

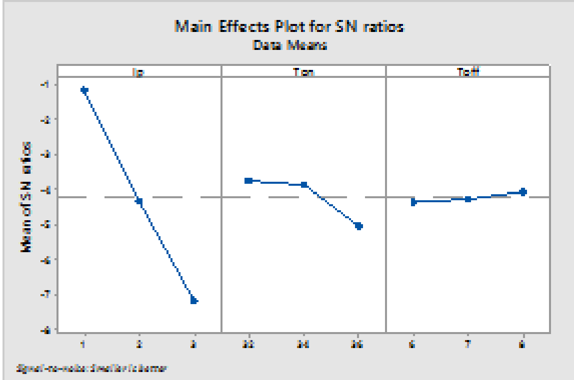

Fig.7.Effects of parameters plot on Ra for SN-ratio of brass wire

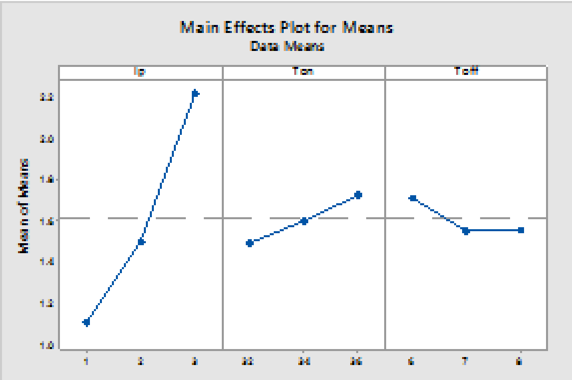

Fig.8.Effects of parameters plot on Ra for mean of Molybdenum wire

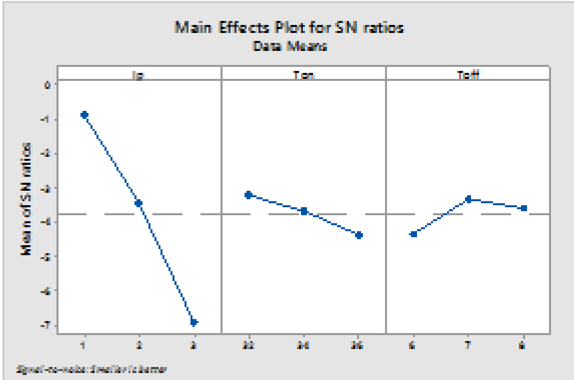

Fig.9.Effects of parameters plot on Ra for SN-ratio of Molybdenum wire

Table.9.ANOVA analysis for material removal rate using Brass wire

Source	Degree of freedom (f)	Sum of squares (SS_A)	Variance (V_A)	FAo	P	Contribution (%)
Current	2	2.96484	1.48242	47.95	0.020	89.16
Pulse on	2	0.01400	0.0070	0.23	0.815	7.16
Pulse off	2	0.24869	0.12434	4.02	0.199	0.8148
Error	2	0.06183	0.03092			2.85
Total	8	3.28936				100

S = 0.175828 R-Sq. = 98.12% R-Sq. (adj) =92.48%

S = 0.364912 R-Sq. = 95.57% R-Sq. (adj) = 82.27%

Table.10.ANOVA analysis for material removalrate usingMolybdenum wire

Source	Degree of freedom (f)	Sum of squares (SS_A)	Variance (V_A)	FAo	P	Contribution (%)
Current	2	1.99700	0.998501	31.19	0.031	86.4699
Pulse on	2	0.16036	0.080180	2.50	0.285	3.4275
Pulse off	2	0.01825	0.009127	0.29	0.778	3.6324
Error	2	0.06403	0.032016			6.4699
Total	8	2.23965				100

S = 0.178931 R-Sq. = 97.14% R-Sq. (adj) = 88.56%

Table.11.ANOVA analysis for surface roughness using Brass wire

Source	Degree of freedom (f)	Sum of squares (SS_A)	Variance (V_A)	FAo	P	Contribution (%)
Current	2	1.91073	0.955364	127.25	0.008	86.4089
Pulse on	2	0.08185	0.040927	5.45	0.155	9.7133
Pulse off	2	0.05079	0.025396	3.38	0.228	0.4623
Error	2	0.01502	0.007508			3.4154
Total	8	2.05839				100

S = 0.0866460 R-Sq. = 99.27% R-Sq. (adj) = 97.08%

Table.12.ANOVA analysis for surface roughness using Molybdenum wire

Source	Degree of freedom (f)	Sum of squares (SS_A)	Variance (V_A)	FAo	P	Contribution (%)
Current	2	5.57625	20.94	20.94	0.046	92.82643
Pulse on	2	0.16244	0.61	0.61	0.621	3.97640
Pulse off	2	0.00298	0.01	0.01	0.989	2.46746
Error	2	0.26632	0.13316			0.729696
Total	8	6.00799				100

CONCLUSION

In this study, the influence of brasswire on the performance of WEDM is compared with molybdenum wire. And, the effect of process parameters on the process performance was determined by performing experiments underdifferent machining conditions. Based on the experimental results and analysis, the following conclusions can be drawn: Experiments results of WEDM of tungsten Carbide indicate peak current and pulse on have significant effect on MRR and surface roughness.

Analysis using Taguchi method shows that the optimized values of current, pulse on and pulse off for MRR is 3,36,6 respectively and for surface roughness is 1,32,6. ANOVA analysis shows that the most influencing parameter is the current for both MRR as well as the surface roughness. Variation of this process parameter cause big change in the MRR and surface roughness.

Compared with brass wire, molybdenum wire which results smoother surface finish and the material removal rate is also more. The optimal combination of process parameters for obtaining maximum MRR through Taguchi method for machining Tungsten carbide using EDM is given below:

Peak current- 3amps
Pulse on time-36 µsec
Pulse off time - 6 µsec

The optimal combination of process parameters for obtaining minimum surface roughness through Taguchi method for machining Tungsten carbide using EDM is given below:

Peak current-1 amps
Pulse on time- 32 µsec
Pulse off time - 6 µsec

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