ANALYSIS OF ENERGY DISTRIBUTION IN EDM PROCESS FOR TUNGSTEN CARBIDE MATERIAL

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ABSTRACT- *It is well established fact that EDM is thermal erosion process. The amount of energy available for this process is generated through plasma. In order to understand the actual amount of energy utilized for machining of WC this work was planned. Experiments have been conducted in a planned sequence to take an account of the total energy input and to find out what part of the energy have been utilized for the purpose of material removal or useful part and how much energy goes waste. This was done to optimize the process parameter so that maximum amount of energy is used for the useful purpose. Some theoretical work in literature has been reported but no evidence of experimental proof has been reported*

Keyboard: EDM, plasma

Introduction

The era of conventional machining, used the machine tools like lathe, shaper and milling machines where the carbon steel was used as a cutting tool which further improved when high speed steel (HSS) tools were introduced. The invention of tungsten carbide tools facilitated the machining and material removal rate (MRR) many folds. With the development of 3D milling machines and machining centers, an innovative and versatile tool for productivity improvement has been developed. Emphasis is on high material removal rates to reduce machining time. The same can be achieved through tungsten carbide cutters. Research and developments are on for developing strategies and parameters to develop the best carbide, geometry, coating combinations to realize good tool lifetime and good price performance ratio. During this period nontraditional machining was also developed and many areas for machining were considered, such as electric sparks, high velocity material jets, pulse magnetic fields, light beams, electro thermal, chemical reactions etc. were considered. These nontraditional methods were discovered to overcome difficulties such as complexity of shape, distortion sensitivity, brittle and hard materials. The solutions due to micro machine, difficult to handle jobs and difficult to machine materials such as cermets, ceramics, metal matrix composites etc. were the area of interest for researchers. For superior performance, machining of components made from such materials to close tolerances and higher surface finish is must.

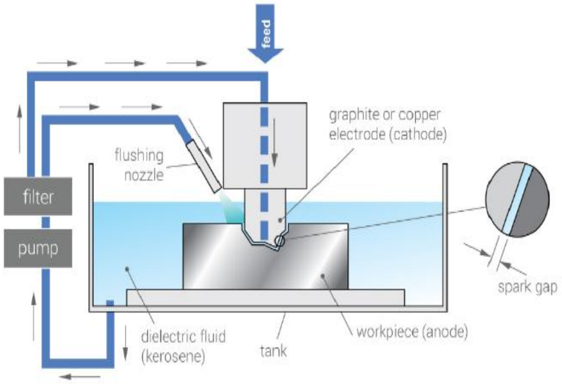

Fig 1: Electro-discharge machining (EDM)

Problem Identification

Machining is an inherent pre requisite manufacturing process to shape any machine component it is well established fact that EDM is thermal erosion process. The amount of energy available for this process is generated through plasma. In order to understand the actual amount of energy utilized for machining of WC this work was planned.

Experiments have been conducted in a planned sequence to take an account of the total energy input and to find out what part of the energy have been utilized for the purpose of material removal or useful part and how much energy goes waste. This was done to optimize the process parameter so that maximum amount of energy is used for the useful purpose. Main parameters and also the related parameters which influence the machining have been described. Input parameters for electro discharge machining as energy includes peak current, pulse duration and polarity which influences the machining has been find out in details.

Experiment & Methodology

In order to monitor the energy experiments were performed in an indigenously designed and fabricated tank. The schematic diagram of the EDM set up is shown in Fig. 4.1(a). Experiments were performed on work piece of diameter 20mm with electrode of the same diameter on both electrodes a hole of diameter 2mm was created to avoid arcing and to facilitate controllable flushing conditions.

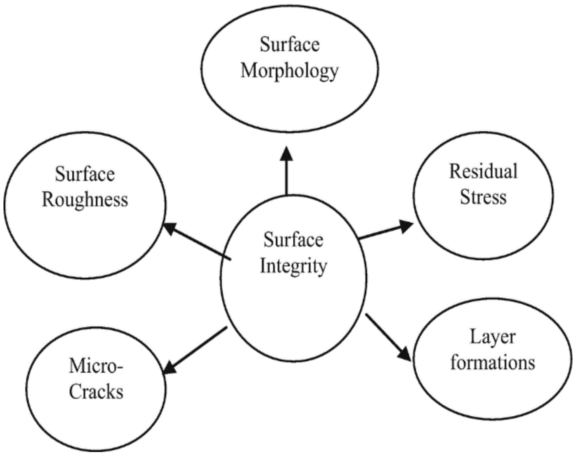

Fig. 2: Surface Integrity in EDM

The temperature of the dielectric was measured at top and the bottom of dielectric fluid which is designated as θd_1 & θd_2 respectively. Tungsten Carbide (P20 grade) was used as work piece material. Copper tungsten (CuW) material having composition tungsten 78% and copper 22% by weight is used as an electrode. CuW has excellent wear characteristics and is suitable for machining of tungsten carbide by EDM. To minimize the energy loss Teflon cover was used in the work piece. The dielectric fluid tank was insulated from outside as shown in Fig. 1(b). The temperature at different locations of work piece, electrode and dielectric fluid was measured with J-type Iron/constantan thermocouples. These thermocouples were attached to temperature indicators which directly measure the temperature with resolution of ± 0.1° C. The volume of material eroded from the work piece was measured at the time when steady temperature was obtained. θ_1& θ_2 are the temperature of the electrode at lower and the upper end while θ_3 & θ_4 are the temperature of the work piece at upper and lower end as shown

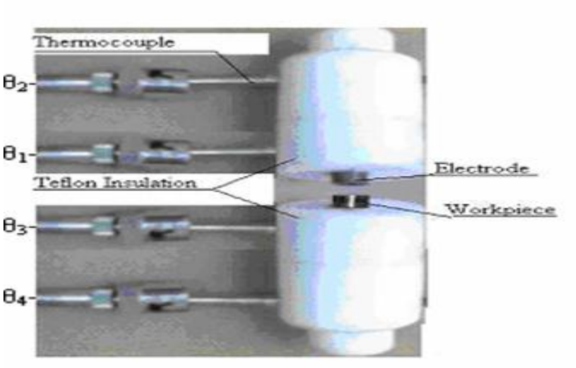

Fig. 3: Workpiece and electrode with insulation and thermocouples

Methodology

Since EDM is basically a thermal erosion process, where plasma (discharge channel) is a surface heat source in which large amount of heat is evolved. Heat which is propagated in the metal as a consequence of thermal conductivity is transmitted through the surface which forms the contact between the discharge channel and the electrode and thus passes into the workpiece [120]. Since the distance between the electrodes is very small in comparison to the electrode dimensions, the scattering of heat in the dielectric layer between the electrodes can be ignored and the heat source can be considered to be a surface one.

The mathematical models for the analysis of EDM process are based on the theory of heat conduction into the solids and use the following differential equation with suitable boundary conditions:

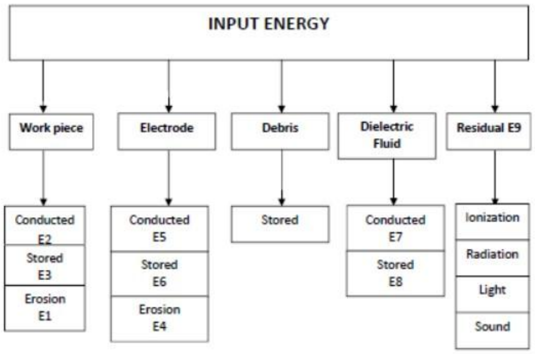

Fig 4: Primary Energy Distribution in EDM Process

The components of the primary energy distribution are defined by the following:

- E_1 - energy for erosion/removal of work piece material

- E2 - energy conducted through the work piece
- E3 - energy stored in the work piece
- E4 - energy for erosion/removal of electrode
- E5 - energy conducted through the electrode
- E6 - energy stored in the electrode
- E7 - energy conducted through the dielectric fluid
- E8 - energy stored in dielectric fluid
- E9 – residual enegies like radiation, light, sound or Ionization

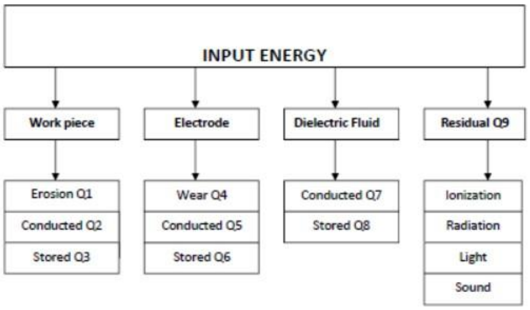

Fig 5: Secondary Energy Distribution in EDM Process

The components of the secondary energy distribution are defined by the following:

Q1 – Heat stored in eroded (from work piece) particles

Q2 – Heat conducted through the work piece

Q3 – Heat stored in the work piece

Q4 – Heat stored in worn (from electrode) particles

Q5 – Heat conducted through the electrode

Q6 – Heat stored in the electrode

Q7 – Heat conducted through the dielectric fluid

Q8 – Heat stored in the dielectric fluid

Q9 – Residual energies like radiation, light & sound energies

During EDM process electrode and workpiece materials are brought closer to each other to start the process of erosion on the surface of workpiece material. Electrode/workpiece with insulation is shown in Fig. 5.3. l_1, l_2 and l_3 are the distances from the point where temperature is taken with the help of thermocouples. The experiments were performed at different currents for different pulse durations which are shown in table 5.1 and 5.2. For each condition minimum of three experiments were performed. The values given in table 5.1 and 5.2 are the average values. From these data MRR values at different current and for different pulse durations were calculated which is shown in table

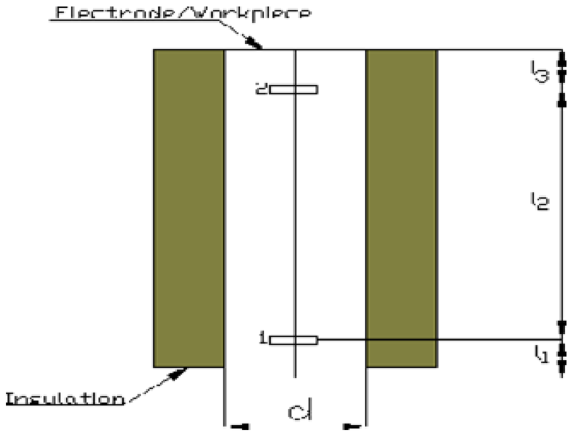

Fig. 6: Electrode/Work piece with Insulation (1&2 are positions of Thermocouples)

Calculation of Energy Distribution

Some of the assumptions made for the calculation of energy distribution during electrical discharge machining are:

The electrodes and the dielectric fluid are considered as continuum in calculating the stored and conducted heats.

The radial conduction in the electrodes and the axial conduction in the dielectric fluid are neglected with respect to the axial and radial components respectively.

A numerical evaluation of the temperature as a function of time and of a single space coordinate enables calculation of the above mentioned components of the secondary energy distribution.

Heat stored in work piece and electrode can be written as:

$$\mathbf{Q_{3,6} = \pi \rho c r^2 l \{ \tfrac{1}{2} [(\theta_1 - \theta_2) . (l_1 - l_3 / l_2) + \theta_1 + \theta_2] - \theta_0 \}}$$

Heat stored in the dielectric fluid Q_8 is calculated by similar linearization of the temperature profile in the dielectric fluid. Now after calculation of the stored energy from the start of machining to the momentary time of measurement t_x, the energy stored per unit of time is approximately obtained from:

$$Q_{3,6,8}=[Q_{3,6,8}(t_x)-Q_{3,6,8}(t_{x-1})]/(t_x-t_1)$$

Q_3 and Q_6 become negligible after a certain time t_x. Thus the transition region from transition to steady state can be determined from the heat stored in the electrodes.

Heat conducted by the work piece and electrode in the axial direction can be written as:

$$Q_{2,5} = \pi d^2{}_{W,E} k_{W,E} (\theta_1 - \theta_2) / 4l_2$$

Heat stored in eroded and worn particles will be:

$$Q_{1,4} = V_{W,E} \rho c (\theta_{d1} - \theta_0)$$

Heat conduction in the dielectric fluid can be written as:

$$Q_7 = 2\pi k_d h_d (\theta_{d1} - \theta_{d2}) / \ln (r_{d2} / r_{d1})$$

The residual energy Q_9 will be:.

Q_9 = Input energy – sum of all other energy components
Energy required to melt and evaporate the eroded particles is calculated as:

$$E1,4 = V_{W,E}. \rho. \{c_{solid} (\theta_M - \theta_0) + S + K_v [c_{liquid} (\theta_V - \theta_M) + R]$$

The components of primary energy distribution are taken as percentage fraction of input energy:

$$M_y = E_y / W_{in} y = 1, 2, 3, \text{--------}, 9$$

The components of the fraction of primary energy distribution are defined by the following:

- M_1 - fraction of energy for erosion/removal of work piece
- M_2 - fraction of energy conducted through the work piece
- M_3 - fraction of energy stored in the work piece
- M_4 - fraction of energy for erosion/removal of electrode
- M_5 - fraction of energy conducted through the electrode
- M_6 - fraction of energy stored in the electrode
- M_7 - fraction of energy conducted by the dielectric fluid
- M_8 - fraction of energy stored in dielectric fluid
- M_9 - fraction of residual energy losses

Table 1: Primary Energy Distribution

Voltage 60V	Pulse Duration (μs)	Work Piece			Electrode			Dielectric		Residual Energy (Watts)
Off Time 20us		Energy stored in Eroded particles (Watts)	Energy conducted through work piece (Watts)	Energy stored (Watts)	Energy stored in worn particles (Watts)	Energy conducted (Watts)	Energy Stored (Watts)	Energy Stored (Watts)	Energy conducted (Watts)	
Current (Amp.)		E1	E2	E3	E4	E5	E6	E7	E8	E9
4	25	0.136	1.081	11.067	0.056	3.245	12.160	0.483	17.640	87.460
4	50	0.195	1.664	21.120	0.127	4.393	22.630	0.485	44.150	76.660
4	100	0.242	2.261	23.600	0.183	5.180	24.600	0.393	52.980	90.570
4	200	0.191	2.431	23.782	0.195	5.690	25.970	0.385	57.870	101.670
10	25	0.185	1.030	20.399	0.057	3.258	40.100	0.510	30.100	237.690
10	50	0.301	1.391	41.499	0.132	5.356	81.214	0.487	74.200	223.980
10	100	0.487	1.656	68.850	0.186	8.387	147.600	0.430	91.300	181.090
10	200	0.532	1.778	87.436	0.199	9.941	189.217	0.457	114.220	141.690
16	25	0.285	1.075	65.493	0.188	4.930	59.990	0.119	35.300	365.950
16	50	0.392	1.461	90.033	0.381	8.450	175.540	0.138	105.870	299.870
16	100	0.515	1.874	112.880	0.454	11.280	214.880	0.147	129.840	328.220
16	200	0.451	2.079	133.530	0.462	12.550	237.120	0.145	149.760	336.610
24	25	0.924	0.682	134.100	0.300	3.664	39.640	0.102	52.880	591.760
24	50	1.255	0.875	153.200	0.513	7.410	112.840	0.111	147.170	605.230

24	100	1.486	1.012	193.320	0.621	10.322	147.480	0.163	176.600	668.930
24	200	1.291	1.117	222.680	0.810	16.084	185.950	0.086	206.040	676.810

Table 2: Percentage Fraction of Energy Distribution

Voltage 60V	Pulse Duration (µs)	Work Piece			Electrode			Dielectric		Residual Energy (%)
Off Time 20µs		Energy stored in Eroded particles (%)	Energy conducted through work piece (%)	Energy stored (%)	Energy stored in worn particles (%)	Energy conducted (%)	Energy stored (%)	Energy stored (%)	Energy conducted (%)	
Current (Amp.)		M1	M2	M3	M4	M5	M6	M7	M8	M9
4	25	0.103	0.810	8.300	0.042	2.430	9.120	0.362	13.230	65.603
4	50	0.115	0.970	12.320	0.074	2.560	13.200	0.281	25.760	44.720
4	100	0.121	1.130	11.800	0.092	2.580	12.300	0.194	26.490	45.293
4	200	0.087	1.110	10.900	0.089	2.610	11.900	0.177	26.530	46.597
10	25	0.055	0.310	6.120	0.017	0.980	12.030	0.150	9.030	71.308
10	50	0.071	0.324	9.683	0.031	1.250	18.950	0.115	17.313	52.263
10	100	0.097	0.331	13.770	0.038	1.680	29.520	0.086	18.260	36.218
10	200	0.098	0.326	16.030	0.037	1.820	34.690	0.083	20.940	25.977
16	25	0.053	0.201	12.280	0.036	0.920	11.250	0.210	6.620	68.620
16	50	0.058	0.213	13.130	0.056	1.230	25.600	0.190	15.440	43.732
16	100	0.064	0.234	14.110	0.057	1.410	26.850	0.180	16.230	41.027
16	200	0.052	0.238	15.300	0.053	1.440	27.170	0.170	17.160	38.570
24	25	0.116	0.085	13.750	0.036	0.460	4.960	0.015	6.610	73.970
24	50	0.122	0.085	14.890	0.050	0.720	10.970	0.013	14.310	58.840
24	100	0.125	0.086	16.110	0.052	0.860	12.290	0.012	14.720	55.750
24	200	0.099	0.086	17.010	0.058	1.100	14.204	0.007	15.740	51.700

The Energy Distribution has been calculated by varying pulse duration and current by using equations given above. During calculations some of the assumptions taken are:

It is assumed that the relative frequency used in equation 5.13 to calculate input energy, ⍰ =1 It is assumed that all the erosion during EDM process is due to melting. However, the energy due to evaporation is negligible i.e. K_V is negligible as shown in equation 5.20 for energy stored in work piece (M3), electrode (M6) and energy conducted by dielectric (M8). The results are given below in table 5.6-5.8 indicate that F and P value are within acceptable limits.

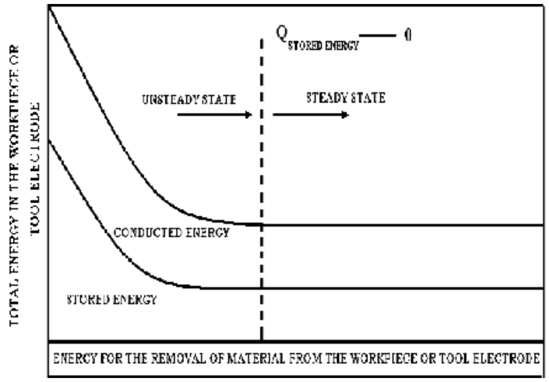

Fig. 7: Variation of energy with respect to time showing transition from transient to steady state

Conclusion

Thermal energy plays a vital role in formation of cracks during machining of WC-Co. The energy is a function of pulse current and pulse duration. Surface cracks are formed due to re- solidified layer which are confined to only few micron of the re-solidified layer. However, at higher discharge current, formation of detrimental phase Co_3W_6C occurs (due to loss of carbon) which causes formation of cracks inside the material which is also affected by difference in coefficient of thermal expansion . Grain size of tungsten carbide plays a vital role in the distribution of cracks and depth of cracks. Larger the grain size more is the possibilities of cracks formation which is extended deeper into the surface due to larger pool of cobalt component occupying the grain boundary. This situation can be redressed by using fine grained work piece material. Current and pulse duration have an optimum value for maximization of MRR for each set of machining .When any one of the two exceeds, the value the MRR decreases.

Future Scope

Energy distribution in EDM is at an infancy stage as yet. A little has been reported on this important aspect. However, it is well proven that energy is the function of pulse current and pulse duration in EDM process. A detailed investigation into this area can play a very important part if an in depth study is carried out, particularly on carbide die materials.

An in-depth study is also required to understand the phase transition during machining as it influences both the MRR and surface roughness. Role of complex carbides also need to be understood more deeply in order to achieve better surface integrity as well as longer life of EDMed die material.

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