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AN EXPERIMENTAL OBSERVATION ON TITANIUM GRADE 5 ALLOY USING CU, CUW ELECTRODE WITH EDM USING REVERSE POLARITY

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Abstract: We are living in the era of advance materials, which are most widely used due to their effective properties such as high strength, wear resistance and light in weight. But manufacturing from these materials is challenging process due to their properties. For this there are various nontraditional machining process which are used for effective machining of these materials. Electrical Discharge machining also contribute a lot in machining of advance materials due to its higher MRR and surface finishing. There is no direct contact between tool and workpiece in EDM. In this study, copper and copper tungsten are used as tool electrode with reverse polarity to investigate the material removal rate (MRR) and tool wear rate(TWR) of the titanium grade-5 (Ti-6Al-4V) with input parameters as current, gap voltage and on time
Keywords—Copper, Copper Tungsten electrode, Titanium grade-5 alloy,MRR,TWR, Reverse polarity

1. INTRODUCTION
Electrical discharge machining is a modern machining which comes under the electro-thermal machining processes in the classification of modern machining methods. In this process material is removed from the work piece due the heat and energy of the beam. It is also known as spark erosion machining or sparks machining because material of workpiece is removed by electric spark. Electrical discharge machining (EDM) is one of the most popular machining techniques to manufacture dies, press tools, complicated shape components of aerospace, automobile and surgical industries. This process is applicable for machining where both cutting tool and workpiece are electrically conductive.EDM process differs from the traditional machining process because there is no direct contact between the electrode tool and workpiece

1.1 Working Principle of EDM:
In the electrical discharge machining the electrical energy is converted into the thermal energy due the sparks produce between the two electrodes i.e the tool and the work material are immersed in a dielectric medium. Generally kerosene or deionizer water is used as the dielectric medium. A gap is maintained between the tool and the workpiece. Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. Generally the tool is connected to the negative terminal of the generator and the workpiece is connected to positive terminal

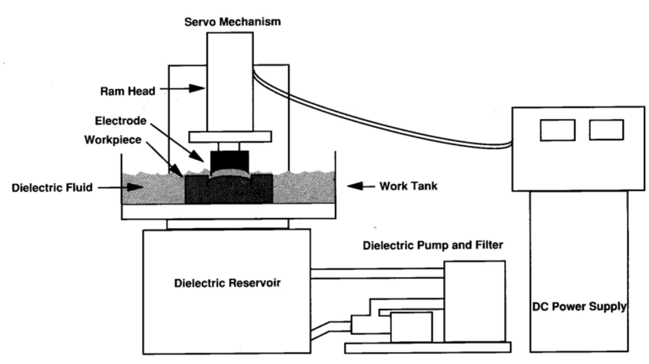

Figure 1 Layout of the EDM process [3]

The bonding energy of the electrons is less when electrode is connected with negative terminal, then electrons would be emitted from the tool and such emission of electrons are called cold emission. The “cold emitted” electrons are then accelerated towards the job through the dielectric medium. As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionization of the

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dielectric molecule depending upon the work function or ionization energy of the dielectric molecule and the energy of the electron. Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions. Large number of electrons will flow from the tool to the job and ions from the job to the tool and visually seen as spark. Thus the electrical energy is dissipated as the thermal energy of the spark. Energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux. Such localized high temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially. As the potential difference is withdrawn, the plasma channel is no longer sustained. As the plasma channel collapse,it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark[4]

1.2 Basic EDM Process Parameters:

Various process parameters are discussed below

Peak current: - When the current increases in the pulse on-time then the used maximum current is called peak current. Peak current is directly proportional to the MRR and inversely proportional to the surface roughness and also increase the tool wear rate due to peak current increases

Discharge voltage: -When the voltage increases then gap between the tool electrode and workpiece also increases. Due to this the flushing of the dielectric fluid becomes adequate. So thus the material rate (MRR), tool wear rate (TWR) and as well as roughness also increases.

Pulse on time: -In the EDM process the pulse on-time expressed in microseconds (μs). A time when the material is removed is called pulse on-time, i.e. working time is called pulse on-time. So this means if the pulse on-time increases then material removal rate is also increase. In other words pulse on-time is directly proportional to the MRR.

Pulse off-time: -The pulse off-time is the time when the tool electrode in interval, i.e. this time material does not removes from the machining gap and this time is flushing time. Thus this time is inversely proportional to the MRR. So if pulse off-time is increases than MRR decreases.

Polarity:-The polarity means negative or positive terminals. In EDM process tool electrode can take at take positive terminal or negative terminal. But from the positive terminal the material removal rate is higher as compare material removal rate at negative terminal due the kinetic energy of the electron. So in EDM should take tool electrode at negative terminal. This means the cathode is tool electrode and the workpiece is anode.

Dielectric flushing: -The dielectric fluid used in EDM have characteristics of high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability, good degree of fluidity and easily available. TWR and MRR are affected by the type of dielectric and the method of its flushing. The different types of flushing are injection flushing, suction flushing, and side flushing and flushing by dielectric pumping.

Electrode material: -There are various factors that determines the suitability of material for electrode such as, maximum MRR, wear ratio, cost and ease with which it can be shaped or fabricated to the desired shape

1.3 Fundamental EDM settings: -

The polarity, pulse duration, pulse interval and peak current are the basic machine settings. These parameters can also be expressed as average current, pulse frequency and duty factor.

Average Current: -It is the maximum current available for each pulse from the power supply/generator in the circuit. Average current is the average of the amperage in the spark gap measured over a complete cycle. It is calculated by multiplying peak current by duty factor. [7]

Average Current (A) = Duty Factor (%) × Peak Current [7]

Pulse Frequency: -It is the number of cycles produced across the gap in one second. The higher the frequency, finer is the surface finish that can be obtained. With an increase of number of cycles per second, the length of the pulse on-time decreases. Short pulse on-times remove very little material and create smaller craters. [7].Pulse frequency is calculated by dividing 1000 by the total cycle time (pulse on-time + pulse off-time) in microseconds.

Pulse Frequency (kHz) = 1000/Total cycle time (μs) [7]

Duty Factor: -Duty factor is a percentage of the pulse duration relative to the total cycle time. Generally, a higher duty factor means increased cutting efficiency. It is calculated in percentage by dividing pulse duration by the total cycle time (pulse on-time + pulse off-time).

Duty Factor (%) = [Pulse duration (μs)/Total cycle time (μs)] × 100 [7]

2. OBJECTIVES AND METHODOLOGY

The main objective of this research is to investigate the effect of machining parameters like gap voltage, gap current, and on time on performance parameters like MRR, TWR,for machining of Titanium alloy using reverse polarity

2.1 Methodology

Following procedure will be adopted for the current study.

(i) To prepare the Copper and Copper Tungsten electrodes of cylindrical shape.

(ii) Design of Experimentation using “Taguchi design of experiments” by selecting levels of various input factors.
a) Preliminary experimentation on EDM setup.
b) Main experiments as per Taguchi design and experiment.
(iii) Calculation of MRR & TWR of machined samples. and electrodes
(iv) Analysis of results.
(v) Conclusions.

Calculation of MRR

The MRR means material removal rate and it is defined as the ratio of the difference between the weight of the workpiece before and after machining to the experimental time. Mathematically:

$$MRR = \frac{\mathrm{WBM} - \mathrm{WAM}}{\mathrm{T}}$$

Where: WBM = Workpiece weight before machining,
WAM = Workpiece weight after machining and
T = Experimental Time

Calculation of TWR

The TWR means the tool wear rate and it is defined as the ratio of the difference between the weight of the tool electrode before and after machining to the experimental time. Mathematically:

$$TWR = \frac{\mathrm{TBM} - \mathrm{TAM}}{\mathrm{T}}$$

Where: TBM = Tool electrode weight before machining,
TAM = Tool electrode weight after machining

3. EXPERIMENTATION AND OBSERVATIONS

Titanium grade-5 alloy (Ti-6Al-4V) workpiece was used in experimental work having dimensions 20mm×20mm. The actual picture of the workpiece with electrical discharge machining is shown in Fig.2

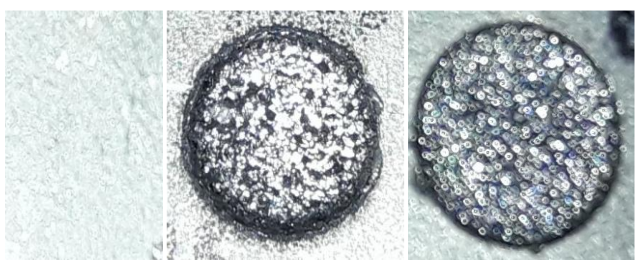

Fig.2. Unmachined surface, machining with Copper electrode, machining with copper tungsten (from left to right)

Titanium (Ti-6Al-4V) has good Mechanical properties
thermal conductivity is 6.60 W/mK and has low density of 4.43 g/cm^{3}with excellent resistance to corrosion.

Material of Tool electrodes

Copper and Copper tungsten were selected as a tool for the electrical discharge machining of the titanium grade 5 alloy. Tool electrode prepared on the lathe machine with 60mm length and 7mm diameter. The copper and copper tungsten tool electrode used in experimental setup is shown in Fig.3. Table 1 shows the physical properties of the copper and copper tungsten material.

Table 1 Physical properties of Copper amd Copper Tungsten tool electrode

S.NO.	Properties	Cu	CuW(75% W,25%Cu)
1	Electrical conductivity at 20 C	5.96*10^7 simens/m	1.83*10^7 simens/m
2	Electrical resistivity	1.96 μΩcm	4.5μΩcm
3	Density	8.96 gm/cc	14.5 gm/cc
4	Specific heat	0.0923Cal/gmK	……
5	Thermal conductivity	268 - 389 W/mK	189W/mK
6	Melting point	1083°C	2820-3500 C

Fig.3 Tool electrodes used in experimental setup

3.1 Electrical Discharge Machining Set Up

The experimental work was carried out on Elektrpuls SE 35 machine tool. The current, voltage and on time are the control parameters which were used in experimental work. The various control parameters were selected for investigate the material removal rate and tool wear rate for copper and copper tungsten tool electrodes are shown in table 2.

Table 2. Input parameters used in EDM

S. No.	**Parameters**	**Description**
1	Workpiece	Titanium Grade-5 (Ti-6al-4V)
2	Tool electrode	Copper, Copper Tungsten
3	Current	5A, 7A and 9A
4	Gap Voltage	50V, 60V and 70V
5	On Time	50, 100 and 150 µs.
6	Dielectric Fluid	Commercial grade EDM oil
7	Workpiece polarity	Negative
8	Tool electrode polarity	Positive
9	Servo system	Electro hydraulic

3.2 Taguchi Method

Experimental design techniques proposed by Dr. Taguchi are extremely important for situations where a new product or a process is to be developed in a cost effective and confident manner. MINITAB-18 software is used to calculate the response Tables, interactions between various parameters and main effects plots. The machining parameters and their levels show in Table 3. First of all, we identified the main function, side effects and failure mode and then the noise factors, testing conditions and quality characteristics. The objective functions to be optimized are also identified with control factors and their levels. L 18 orthogonal mixed array was selected for this study, because one parameter has two levels and rest parameters have three levels

Table 3. Design of experiment of L18 orthogonal array

S. No.	**Tool Electrode**	**Current**	**On Time**	**Gap Voltage**
1.	Cu	5	50	50
2.	Cu	5	100	60
3.	Cu	5	150	70
4.	Cu	7	50	50
5.	Cu	7	100	60
6.	Cu	7	150	70
7.	Cu	9	50	60
8.	Cu	9	100	70
9.	Cu	9	150	50
10.	CuW	5	50	70
11.	CuW	5	100	50
12.	CuW	5	150	60
13.	CuW	7	50	60
14.	CuW	7	100	70
15.	CuW	7	150	50
16.	CuW	9	50	70
17.	CuW	9	100	50
18.	CuW	9	150	60

4. RESULTS AND DISCUSSIONS

MRR, TWR were found from the input parameters (electrode materials, current, on time and gap voltage) using Taguchi method, which helps in reducing the number of experimental runs from 54 to 18. The significance and interactions between numerous variables were also seen by plotting S/N curves and interaction plots.

4.1 Analysis of Material Removal Rate

After processing all the samples of titanium grade-5 (Ti-6Al-4V) using electrical discharge machining, the mass removal per minute was found .Each run was carried out for 20 minutes and MRR per minute was calculated.. The values of MRR for all the machining tests are presented in the Table 4.

The mean effect plots of the S/N ratio for MRR at different levels using signal-to-noise “larger is better” are shown in Fig. 4 which reveals that the MRR is maximum at 1st level of tool electrode (copper), 3rd level of current, 3rd level of on time and 2nd level of gap voltage parameter. Thus the S/N ratio shows that E_1, C_3, T_3, and V_2 parameter set give the maximum MRR. Main effects plot for S/N ratio of MRR also reveals that copper tool electrode gives higher material removal rate as compared to copper tungsten tool electrode due to higher electrical conductivity and thermal conductivity of copper tool electrode and current is directly proportional to MRR for both tool electrodes,by increasing current, the electrical discharge energy and impulsive force are increased and this issue leads to more material removal rate for both tool electrodes.

Table 4. Response Table for the MRR

S. No	Tool Electrode	Current	On Time	Gap Voltage	MRR
1.	Cu	5	50	50	0.002518
2.	Cu	5	100	60	0.002611
3.	Cu	5	150	70	0.002793
4.	Cu	7	50	50	0.004223
5.	Cu	7	100	60	0.004317
6.	Cu	7	150	70	0.004166
7.	Cu	9	50	60	0.004973
8.	Cu	9	100	70	0.005201
9.	Cu	9	150	50	0.005169
10.	CuW	5	50	70	0.001211
11.	CuW	5	100	50	0.001258
12.	CuW	5	150	60	0.001343
13.	CuW	7	50	60	0.001478
14.	CuW	7	100	70	0.001543
15.	CuW	7	150	50	0.001577
16.	CuW	9	50	70	0.001745
17.	CuW	9	100	50	0.001708
18.	CuW	9	150	60	0.001895

On time and gap voltage also affect the MRR, but doesn’t give significant results. The electrical conductivity, thermal conductivity and melting point of the electrode and workpiece material play an important role in EDM.

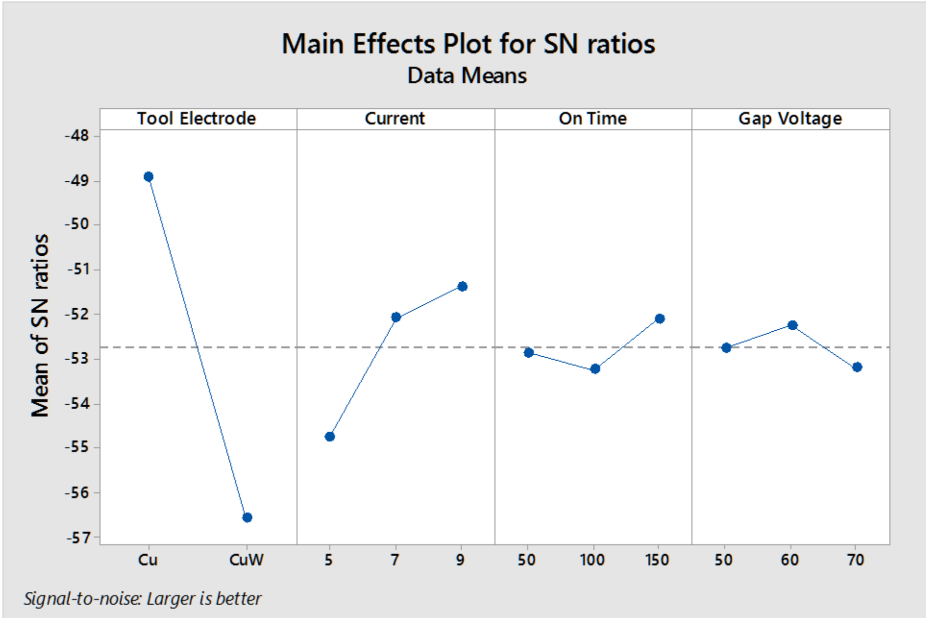

Fig.4. Mean effect plot for S/N ratios for material removal rate

The interaction plot for S/N ratio of MRR reveals that the lines of the MRR are converging from one end to the other end. So the interactions between the MRR and current are significant, which are shown in Fig.5

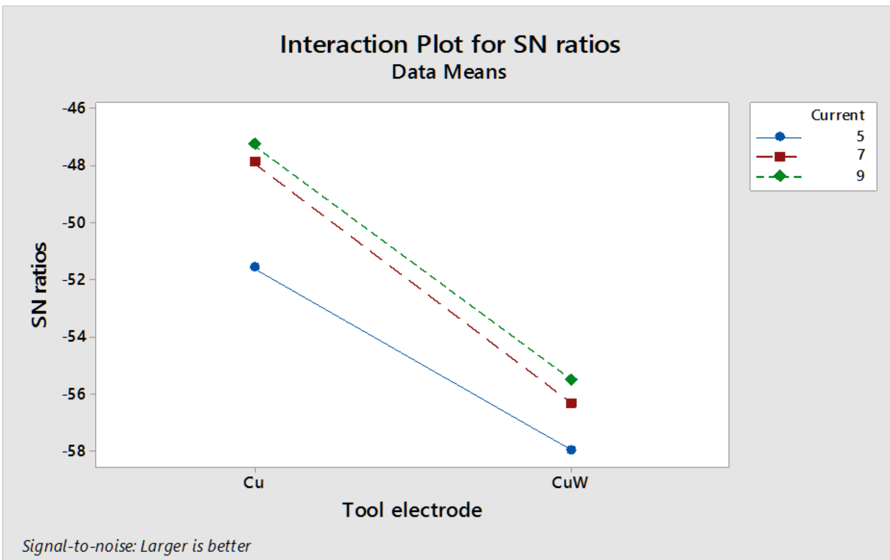

Fig.5 Interactions plot of S/N ratio for MRR

4.2 Analysis of Tool Wear Rate

The tool wear rate for the two electrodes was found out using a weighing balance. Each experiment was carried out for 20 minutes and TWR per minute was calculated as shown in table 7.The mean effects plot of the S/N ratio for TWR at different levels using signal-to-noise "smaller is better" is shown in Fig. 7which reveals that the TWR is minimum at 2^{nd} level of tool electrode (copper tungsten), 1^{st} level of current, 1^{st} level of on time and 1^{st} level of gap voltage parameter. Thus the S/N ratio shows that E_2, C_1, T_1, and V_1 parameter set gives the minimum TWR. Main effects plot of S/N ratio for TWR reveals that copper tungsten

Table 7. Response Table for TWR

S. No.	Tool Electrode	Current	On Time	Gap Voltage	TWR
1	Cu	5	50	50	0.000026
2	Cu	5	100	60	0.000151
3	Cu	5	150	70	0.000326
4	Cu	7	50	50	0.000548
5	Cu	7	100	60	0.001001
6	Cu	7	150	70	0.001064
7	Cu	9	50	60	0.001451
8	Cu	9	100	70	0.001567
9	Cu	9	150	50	0.001255
10	CuW	5	50	70	0.000019
11	CuW	5	100	50	0.000057
12	CuW	5	150	60	0.00012
13	CuW	7	50	60	0.000209
14	CuW	7	100	70	0.000404
15	CuW	7	150	50	0.000567
16	CuW	9	50	70	0.000654
17	CuW	9	100	50	0.000706
18	CuW	9	150	60	0.000684

Tool electrode gives lower tool wear rate as compared to copper tool electrode. This is because the copper tungsten tool electrode have higher melting point compared to copper tool electrode, which causes less wear of copper tungsten tool electrode. The Current is directly proportional to TWR for both tool electrodes because of increasing current, the electrical discharge energy and impulsive force are increased and this issue leads to more tool wear rate.Thus the copper tool electrode gives a higher material removal rate with higher tool wear rate as compared to copper tungsten tool electrode.

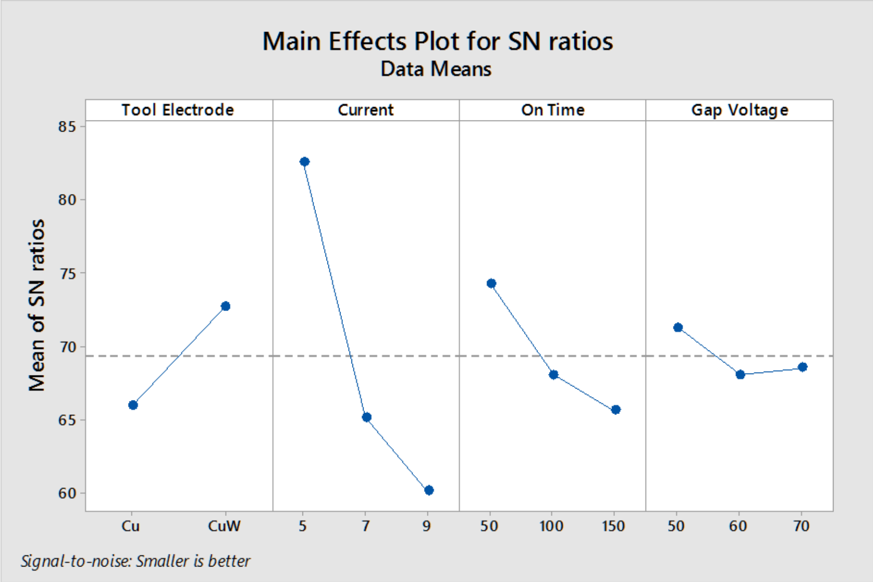

Fig.6 Mean effect plot for S/N ratios for tool wear rate

The interaction plot ofthe S/N ratiofor TWR reveals that the lines of the TWR are converging from one end to the other end which is shown in Fig. 7. Hence the interactions between the TWR and current are significant

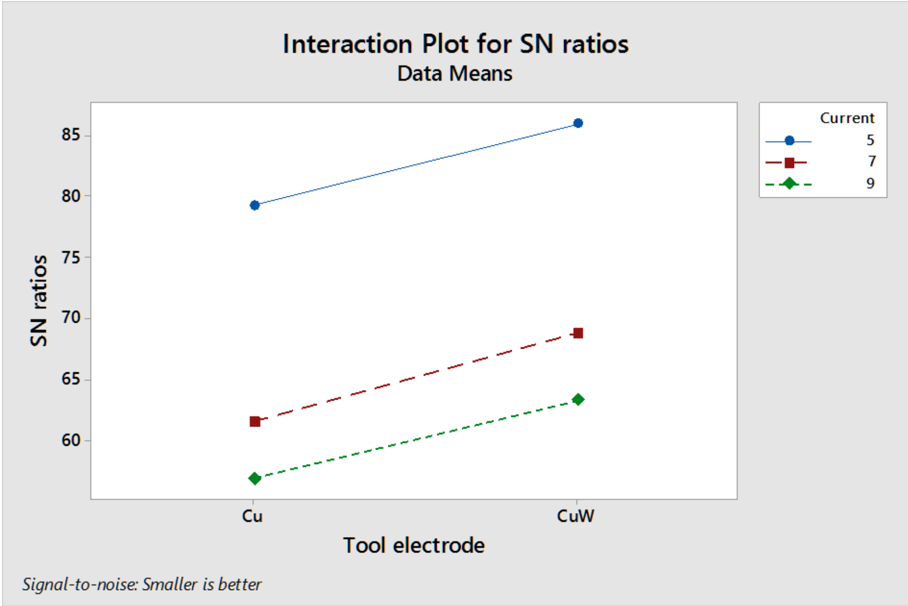

Fig.7 Interactions plot of S/N ratio for TWR

5. CONCLUSION

After analyzing the results of the experiment performed on titanium alloy grade-5 (Ti-6Al-4V) with different electrode materials in spark electrical discharge machine, following conclusions are derived for MRR and TWR

1.For the Titanium (Ti-6Al-4V) work material, Copper tool electrode offers higher MRR as compared to the machining performed by Copper Tungsten tool electrode.

2.Copper Tungsten electrode gives lower TWR as compared Copper tool electrode.

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