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Development of new metal matrix composite electrodes for electrical discharge machining through powder metallurgy process

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Electrical discharge machining (EDM) is one of the widely used nontraditional machining methods to produce die cavities by the erosive effect of electrical discharges. This method is popular due to the fact that a relatively soft electrically conductive tool electrode can machine hard work piece. Copper electrode is normally used for machining process. Electrode wear rate is the major drawback for EDM researchers. This research focus on fabrication of metal matrix composite (MMC) electrode by mixing copper powder with titanium carbide (TiC) and Tungsten carbide (WC) powder through powder metallurgy process, Copper powder is the major amount of mixing proportion with TiC and WC. However, this paper focus on the early stage of the project where powder metallurgy route was used to determine suitable mixing time, compaction pressure and sintering and compacting process in producing EDM electrode. The newly prepared composite electrodes in different composition are tested in EDM for OHNS steel.

Keywords: Electrical Discharge Machining; EDM Electrode; Metal Matrix Composite.

1. Introduction: Electrical discharge machining (EDM) is the most extensively used non-conventional material removal process to machines hardened tool steel. EDM is carried out by means of electric sparks that jump between electrode and workpiece subjected to a voltage and submerged in a dielectric fluid. Since there are no direct contact between the electrodes and the workpiece, EDM eliminates the mechanical stresses, chatter and vibration arising during the machining. EDM is widely used to manufacture mold, die, and automotive, aerospace and surgical components [1]. EDM electrodes have the mirror image of the desired products. Surface finish, dimensional accuracy, geometry of electrodes and material properties are among the parameters affecting the machining performance. This thus led to manufacture of several electrodes for a production of single product that has complex geometry, which result in increase of tooling cost [1 - 12].

2. Experimental setup: Two different routes will be used to produce MMC EDM electrodes in this study. Powder metallurgy method was used as preliminary study in order to determine the best composition ratio and best sintering temperature. The experiment flow chart is shown in figure (1).

2.1 Material Characteristics:
A) Copper Powder: It is one of the most widely used nonferrous metals in industry. Copper is soft and ductile that is difficult to machine and also it has an almost unlimited capacity to be cold-worked. Furthermore, it is highly resistant to

corrosion in diverse environments including ambient atmosphere, sea water and some industrial chemicals. The mechanical and corrosion resistance properties can be improved by alloying.

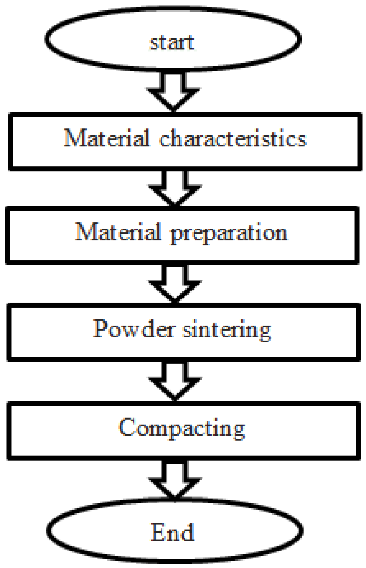

Figure (1) Experimental Flow Chart.

Figure (2) Copper powder.

(B) Titanium Carbide powder: TiC (black colored powder) is extremely hard refractory ceramic material and has sodium chloride (face centered cubic) crystal structure. It is used in preparation of cermets which are in turn used to machine steel materials at high cutting speed. Another use is in abrasion-resistant surface coatings on metal parts such as tool bits. It is also used as thermal barrier coating (TBC) in spacecrafts.

Figure (3) Titanium Carbide powder.

(C) Tungsten Carbide (WC) powder: Tungsten carbide (WC) is usually a fine gray colored powder and used in cutting tools, abrasives, armor-piercing rounds, tools and instruments, and jewelery. It is stiffer than steel with a Young's modulus of about 550 Gpa. It is much denser than steel as well as titanium. It's hardness is comparable to that of corundum (α-Al_2O_3), sapphire and ruby. It can only be polished and finished with abrasives of superior hardness such as cubic boron nitride and diamond.

Figure (4): Tungsten Carbide powder.

TABLE (1) PROPERTIES OF CU, TiC, WC

	29 Cu 63.546	TiC 59.89	WC 195.86
Melting Point °C	1083	3140	2870
Boiling Point °C	2595	4820	6000
Density G/Cm^3	8.94	4.93	15.63
Mohs Hardness @ 20 °C	3.0	9-9.5	9
Elec Conductance Microhm	0.593	180-250	80
Crystal Structure	Cubic, Face Centered	Cubic	Hex

TABLE (2) Metal Powder Details

	$_{29}Cu^{63.546}$	$TiC^{59.89}$	$WC^{195.86}$
Supplier Name	The Metal powder Company Ltd	Royal Scientific Suppliers	Royal Scientific Suppliers
Make	MEPCO	ALFA AESAR	ALFA AESAR
Purity level	99.5	99.5%	99.5%
Particle Size	1 micron	1 micron	1 micron

2.2 Material Preparation: For powder compaction method, mixing ratios were determined by weight. Increase the 2 % of weight Titanium Carbide was added to the total weight of Cu mixtures and increase 5 % of weight Tungsten Carbide to the total weight of Cu mixtures. Mixing of component materials were done using ball mill for 20 minutes in 100 rpm to ensure that the component materials are well mixed. Table (4) shows the mixing ratio of component materials that were used in this study.

TABLE (3): MIXING RATIOS OF COMPONENT MATERIALS FOR MMC EDM ELECTRODE

Material	Mixing ratio (% wt)				
	1	2	3	4	5
Copper	98	96	94	92	90
Titanium Carbide	2	4	6	8	10

Material	Mixing ratio (% wt)				
	1	2	3	4	5
Copper	95	90	85	80	75
Tungsten Carbide	5	10	15	20	25

2.3 Metal powder weight calculation

Density of copper = 8.94 gm/cm3

Density of Titanium Carbide = 4.93 gm/cm3

Density of Tungsten carbide = 15.63 gm/cm3

Diameter of electrode = 12mm

Length of electrode = 40mm

Volume $v = \frac{\pi}{4} d2 \times L$

Weight of metal powder = Density × Volume

TABLE (4): METAL POWDER WEIGHT CALCULATION (Cu-TiC)

Composition	Individual weight (gm)	Total weight (gm)
Cu-90% + TiC-10%	36.4 + 2.23	38.63
Cu-92% + TiC-8%	37.21 + 1.78	38.99
Cu-94% + TiC-6%	38.02 + 1.34	39.36
Cu-96% + TiC-4%	38.83 +0.89	39.72
Cu-98% + TiC-2%	39.63 + 0.45	40.08

TABLE (5): METAL POWDER WEIGHT CALCULATION (Cu-WC)

Composition	Individual weight (gm)	Total weight (gm)
Cu-95% + WC-5%	38.42 + 3.54	41.96
Cu-90% + WC-10%	36.4 + 7.07	43.47
Cu-85% + WC-15%	34.38 + 10.61	44.99
Cu-80% + WC-20%	32.35 + 14.14	46.49
Cu-75% + WC-25%	30.33 +17.68	48.01

2. 4 Die & Punch details: It used to form the tools. The bush is placed inside the die.

Die material: Oil hardening non shrinkage die steel.

Bush size:

Outer diameter : 30mm

Inner diameter : 12mm

Length : 140mm

Punch size:

Diameter : 12mm

Length : 85mm

Size of the electrode:

Length : 30mm

Diameter : 12mm

Figure (5): OHNS Die setup.

Figure (6): Inner Bush OHNS Material.

Figure (7): Heat treated pin.

2.5 Universal Testing Machine: The compacting process was carried out in the Universal Testing Machine with the maximum load of 40 ton capacity.

Figure (8): Analog type Universal testing machine.

2.6 Powder Metallurgy process: Metal powder is heated in a controlled-atmosphere furnace to a temperature below its melting point, but high enough to allow bonding of the particles. The mixed Cu powder samples were the sintered to improve their mechanical properties. Sintering was done in open hearth or fire furnace for 60 minutes at 866 °C, 921 °C and 975 °C which were 80, 85 and 90 % of the melting temperature of copper respectively to determine the optimum sintering temperature.

Figure (9) Metal powder heated in open fire furnace.

Compaction Process: The heated metal power is pressed in die under high pressure to form them into the required shape. The work part after compaction is called a green compact or simply a green, the word green meaning not yet fully processed. Compaction of Cu mixed powder was done in order to determine suitable compaction pressure.

The powders were compaction with the help of oil hardening non shrinkage die. It's having a punch and dummy piece. The punch is used both to give the load to powder for compaction and also to take the workpiece out of die after the process.

Zinc stearate was used to lubricate the punch and inner surface of dies. This will enable us to take the tool out of the die very safely without breaking. The zinc stearate is able to prevent the sticking of powder mix to other surfaces.

A known amount of heated powder by weight was taken and poured into the die with its butt or dummy piece at the end. Now we introduced the punch into the die. Compacting load was applied onto the punch by placing the whole apparatus inside the universal testing machine which operates hydraulically.

The mixed powders were compacted at 30 KN respectively to produce cylinder sample with diameter 12 mm. The ejection of compact was done by removing butt and placing die over two parallel blocks of same height leaving the hole right in the free space between the two and then applying the pressure by means of hydraulic press or UTM.

Figure (10): Compacting process in UTM.

2.7 Developed Composite Electrodes:

Figure (11): MMC Electrodes Cu with TiC.

Figure (12): MMC Electrodes Cu with WC.

3. Conclusion: Through powder metallurgy process the MMC electrodes are prepared for each five composition in both copper and titanium carbide and copper and tungsten carbide combination.

Though the electrodes can make in to complex shape it was done as 12 mm cylindrical rods which may be used for the purpose of drilling. The diameter can also vary for the suitable practical application

Further it is planned to conduct the EDM experiments by varying the parameters like current, voltage, pulse on time & pulse off time and find the optimum condition to obtain better metal removal rate and lesser tool wear rate.

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