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Study of Machining Parameters by Pure Copper and Brass Powder Metallurgy Tool Electrode in EDM

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Abstract
In manufacturing today powder metallurgy has become competitive with processes such as casting, forging and machining particularly for relatively complex parts made of high-strength and hard alloys. Recent advances in this technology now permit manufacture of structural parts of aircraft such as landing gear, engine mount supports, engine disks, impellers and engine nacelle frames to be made by powder metallurgy operation. The aim of this paper is to design an appropriate electrode for EDM equipment by powder metallurgy operation. Based on appropriate design conditions and economic factors this paper performs a detailed study on various air cooled and furnace cooled Cu and brass electrodes and the most appropriate electrode is chosen so that machining with the electrode would be suitable for carrying out large machining operations. EDM gives highly accurate dimensional tolerances and better surface finish. So the whole paper investigates the appropriate electrode and proper production and machining parameters to optimize the machining costs occurring during machining by EDM. From production point of view the electrodes fabricated by powder metallurgy technique is more economical than electrodes manufactured by other manufacturing processes. Based on the economic considerations, quality factors and ease of availability copper and brass were selected as appropriate materials for the electrode. Comparatively air cooled copper electrode was found to be more suitable than brass electrode for machining on EDM.

Keywords: *Powder metallurgy, EDM, air cooled and furnace cooled Cu and brass electrode*

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INTRODUCTION

EDM is the most versatile machining tool in today's manufacturing world. In EDM the comparison of physical, mechanical and electrical properties of electrodes by hardness test, microstructure and study have considerable influence on the process performance in term of material removal rate, electrode wear and depth of cut of work piece [1, 2]. Powder metallurgy is a kind of process in which the metal parts are made by compacting fine metal powders in suitable dies and sintering (that is heating without melting)[3].The commonly used metals in powder metallurgy are iron, copper, aluminum, tin, nickel, titanium and refractory metals. For parts made of brass, bronze, steels and stainless steels pre-alloyed powders are used where each powder itself is an alloy [4–6]. In this paper as pure copper and brass powders are taken so that the process of blending can be eliminated. To create different shapes on Work piece, the flexibility of making the electrode is a must, taking in to account all economic conditions P/M process is chosen as the most versatile method of making electrode of any shape and size as per the requirement. Here pure copper and pure brass electrodes are taken at different quenching conditions to study MRR, depth of cut, and Electrode wear rate at different peak current, pulse-on-time, and duty cycle keeping the machining time constant. Our aim of this paper is to co-relate the properties among copper and brass electrodes and finding out the most suitable electrode [7–10].

MATERIALS AND METHODS

As per specifications copper and brass powders of size 30-40 microns and purity of

Cu is about 99.75%. Brass being an alloy the main constituent is copper (56.7%) and zinc (39.85%) and rest constituents in very less percentages is taken. For this paper the cylindrical electrodes of circular cross-section is being selected. For this dies with cylindrical cavity of circular cross-section is selected.

The die is made of A2 die steel which is medium alloyed and air hardened suitable for cold working. Powder is then poured into a cylindrical die, having walls layered with thick greese (for easy removal), gradually. At first the pressing of powder is being done manually by rotating the screw of the screw press. And then copper powder and brass powder is compressed to $410\,MPa\,(6\,tonnes)$ in the screw press as indicated by its instrumentation panel of control unit to obtain a highly dense green compact. With this pressure the density of the copper green compact was estimated to be around $6.5\,g/cm^3$ and for the brass it was estimated to be around $8.1\,g/cm^3$ .Then the compacts are sintered in the furnace under a controlled atmosphere in the furnace to a temperature below the melting point of copper and brass sufficiently high to allow bonding of the individual particles. The sintering times for both copper and brass are taken to be 60 minutes and the sintering temperatures for copper were selected to be $850\ ℃$ and that of the brass electrode is$600\ ℃$. Then the sintered electrodes are cooled by two ways. One is by air cooling (by natural convection currents)and other is by furnace cooling(allowed to cool within the furnace chamber after switching off the furnace).Now the mild steel work piece is fixed in the fixture in a tank containing dielectric fluid (DEF-92) in an EDM machine which is controlled by numerically controlled systems and by servo mechanism .In EDM Peak current $50\ \mathrm{A}, 45\ \mathrm{A}$ and 40 :, Pulse-on time: $1000\ \mu s, 500\ \mu s$ and $750\ \mu s$, Duty cycle: $12, 10$ and 8 ,Machining time: 30 minutes are taken.

RESULT AND DISCUSSION

After sintering the characteristics of various samples are shown below in Table 1.

Table 1: *Characteristics of Brass Electrode Before and After Sintering.*

Samples No	Type of cooling	Sintering Time (min)	Copper (sintering temp 850°C)				Brass (sintering temp 600°C)			
			Before sintering		After sintering		Before sintering		After sintering	
			Weight (g)	Height (mm)	Weight (g)	Height (mm)	Weight (g)	Height (mm)	Weight (g)	Height (mm)
S_1	furnace	60	12.53	22.5	11.61	28.2	6.86	13.6	7.0	15.0
S_2			9.51	16.7	8.85	19.9	7.37	14.2	7.68	17.0
S_3	air		7.43	13.0	6.91	13.5	3.66	7.8	3.7	8.4
S_4			12.28	23.2	11.23	24.8	6.47	13.7	6.64	15.0

Some contrasting features are observed in both cooper and brass electrodes after sintering. In case of brass electrodes the height and the weight of the electrodes increase for a given area of cross-section. It is because brass is an alloy and liquid phase sintering happened with brass material which has increased the sintered density of the electrode and thus its weighs more.

And in case of copper although height increases but the weight of the electrode decreases for a given area of cross-section. It is due to solid phase sintering happened with copper electrode which has reduced the sintered density of the electrode and thus the reduced weight.

HARDNESS TEST OF ELECTRODES

Then the hardness of sintered electrodes is quantified by Vickers hardness test with a diamond indenter in form of a square based pyramid is used and the hardness number of electrodes is measured in terms of Vickers Pyramid Number (HV). The measured hardness values of the copper and brass electrodes are given in the following tables by using a load of $50\,\mathrm{gf}$, a duel time of 10 seconds and at an indentation angle of $136°$. And as load used is $50\,\mathrm{gf}$ so the hardness number is Micro-Vickers hardness test. And the Vickers hardness number can be noted from the instrumentation panel of the Vickers hardness tester.

Table 2: *Vickers Hardness Number of Brass and Copper Electrode*

Load: 50 gf ,**Duel time:** 10 sec, **Indentation angle:** 136°		
Sample no	Vickers Hardness Number	
	Brass	Copper
S_1	33.3 HV	19.6 HV
S_2	36.5 HV	25 HV
S_3	34.0 HV	18.4 HV
S_4	33.4 HV	21.3 HV
Average	34.3 HV	21.07HV

The Vickers hardness number for copper electrode was found to be 20.92 HV and the Vickers hardness number for the brass electrode was found to be 34.3 HV.Hence the brass electrode is much harder than copper electrode as Vickers hardness number of brass electrode is more than that of copper electrode which affects its strength. Thus brass electrodes are easily susceptible to plastic deformation in comparison to copper electrodes. The surface of the sintered electrodes is quite rough and it requires proper finishing. So it needs to be polished by emery polishing paper of grade 1/0, grade 2/0, grade 3/0 and grade 4/0.

Then the polished electrodes were placed under optical microscope as shown in Figure 1 to observe its microstructure (Table 2).

MICRO STRUCTURE

The microstructure of copper and brass electrodes are observed in an optical microscope. The maximum normal magnification of ocular lens is 10X and minimum normal magnification for objective lens is 50X and maximum normal magnification of objective lens is 100X. And this combination finally gives rise to maximum magnification of 1000X under which the electrodes are observed.

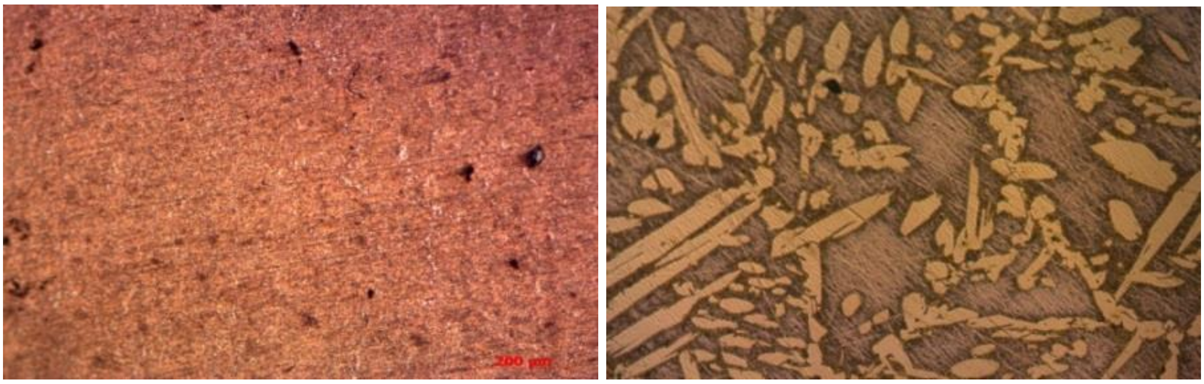

Fig. 1: *Microstructure of Copper and Brass Electrode to a Magnification of 1000X.*

Effect of P/M Electrode on EDM Process

Now the mild steel work piece is fixed in the fixture in a tank containing dielectric fluid (DEF-92) in an EDM machine which is controlled by numerically controlled systems and by servo mechanism. The work piece selected is mild steel and machining time is 30 min (Table 3).

From above observation, it is found that with copper and brass electrodes fabricated by powder metallurgy technique produces more depth of cut and have higher material removal rates even if electrode wear rates of solid copper and brass electrodes are less than that of copper and brass electrodes fabricated by powder metallurgy technique.

Also from above observations it seems copper electrodes have higher depth of cuts and material removal and lower electrode wear rates in comparison to brass electrodes. And also air cooled electrodes have slightly higher material removal rates and depth of cuts and slightly lower electrode wear rates in comparison to the furnace cooled electrodes.

Table 3: *Analysis of Furnace Cooled Copper and Brass Electrodes on Electrical Discharge Machining.*

Type of cooling	Electrode	Sample No	Peak current (A)	Pulse-on time (μs)	Duty cycle (ζ)	Depth (mm)	MRR $\left(\frac{mm^3}{min}\right)$	EWR $\left(\frac{mm^3}{min}\right)$
Furnace cooling	Cu	S_1	50	1000	12	4.19	6.41	4.53
		S_2	45	500	10	4.22	2.99	0.74
		S_3	40	750	8	5.7	4.7	0.74
	Brass	S_1	50	1000	12	4.58	5.98	5.09
		S_2	45	500	10	4.25	2.99	0.78
		S_3	40	750	8	5.67	4.27	1.17
Air cooling	Cu	S_1	50	1000	12	5.4	5.55	4.49
		S_2	45	500	10	4.27	3.41	0.37
		S_3	40	750	8	5.68	5.98	1.12
	Brass	S_1	50	1000	12	5.56	5.12	5.09
		S_2	45	500	10	4.2	2.9	1.17
		S_3	40	750	8	5.6	5.55	1.56

Graphical Analysis of Parameter

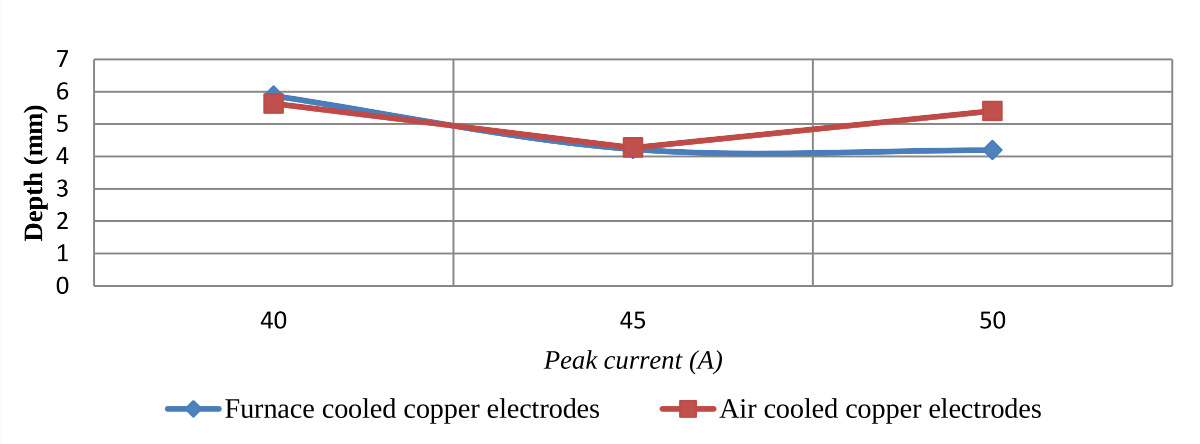

Fig. 2: *Peak Current vs. Depth of Air Cooled and Furnace Cooled Copper Electrodes.*

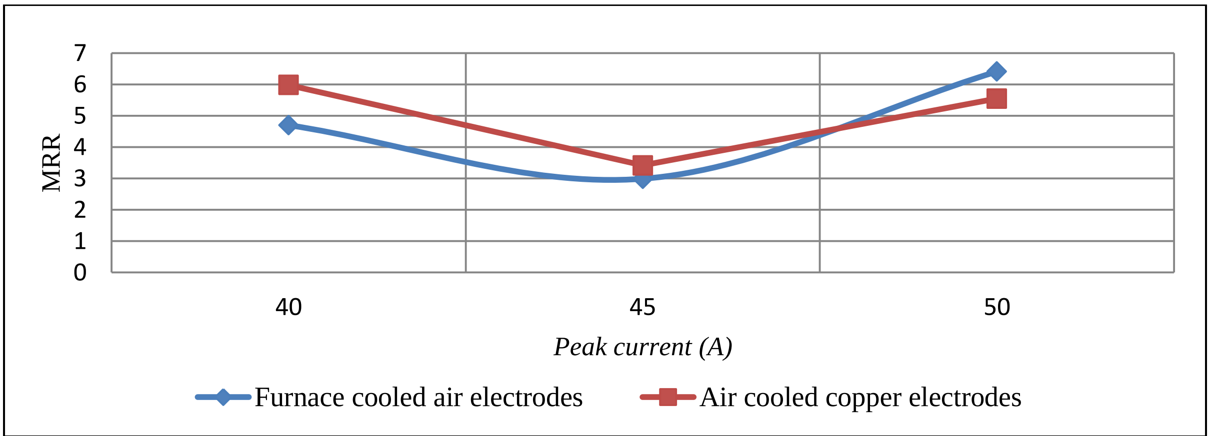

Fig. 3: *Peak Current Vs. MRR of Air Cooled and Furnace Cooled Electrodes.*

At low peak currents the depth of cut produced by furnace cooled copper electrode is slightly more than air cooled copper electrode and at medium peak currents the depth of cut produced by both furnace cooled and air cooled electrode re almost same. But at high peak currents the depth of cut produced by air cooled copper electrode is much more than that of furnace cooled copper electrode. But at low peaks currents the air cooled copper electrode produces larger material removal rates than furnace cooled copper electrode. And at medium peak currents the material removal rate produced by air cooled copper electrode is slightly more than furnace cooled copper electrode. But at high peak currents the furnace cooled copper electrode has more material removal rates than air cooled copper electrode (Figures 2 and 3).

At low peak currents the electrode wear rate of air cooled copper electrode is slightly more than furnace cooled copper electrode. And at medium peak currents the electrode wear rate of furnace cooled copper electrode is slightly more than air cooled copper electrode. And at high peak currents the electrode wear rate of air cooled copper electrode and furnace cooled copper electrode is almost same. So air cooled copper electrodes are better than furnace cooled copper electrodes as they have higher material removal rates and produces larger depth of cuts and have almost same electrode wear rates as furnace cooled copper electrodes (Figure 4).

At low and medium peak currents the depth of cut produced by furnace cooled and air cooled brass electrode are almost same. But at high peak currents the depth of cut produced by air cooled brass electrode is more than furnace cooled brass electrode (Figure 5).

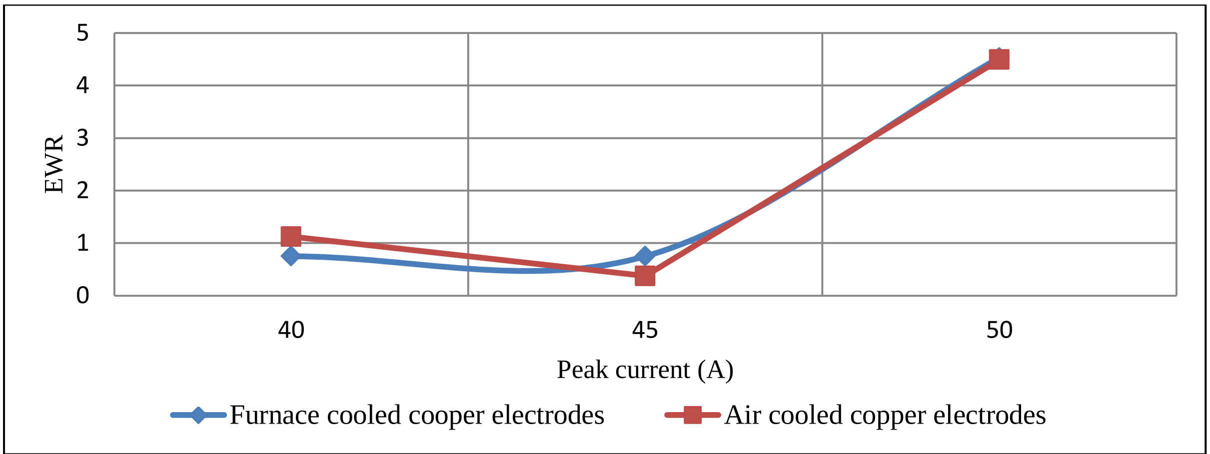

Fig. 4: *Peak Current vs. EWR of Air Cooled and Furnace Cooled Copper Electrode.*

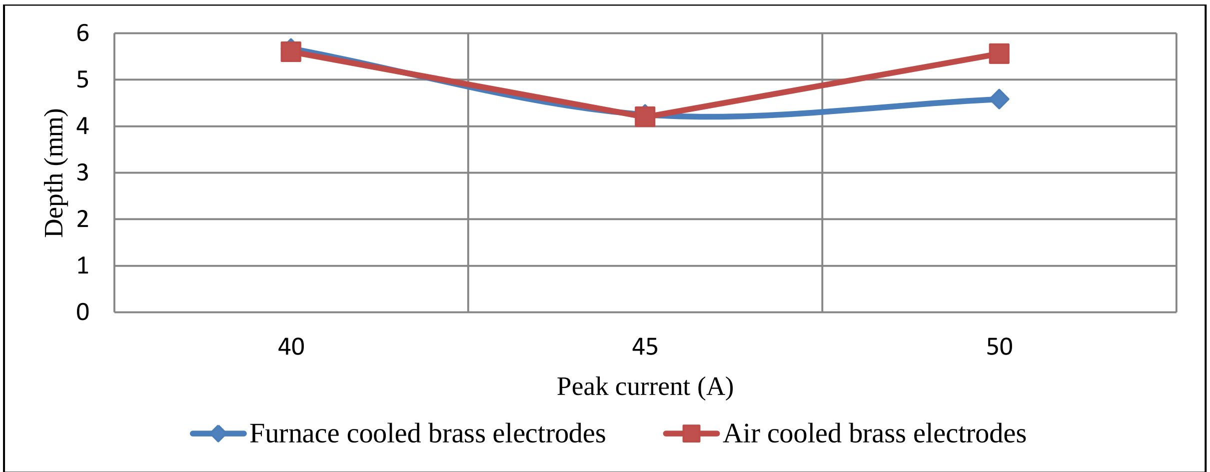

Fig. 5: *Peak Current vs. Depth of Air Cooled and Furnace Cooled Brass Electrodes.*

At low peak currents the air cooled brass electrode has larger material removal rates than furnace cooled brass electrode. And at medium peak currents the material removal rates of air cooled and furnace cooled brass electrode are almost same. And at high peak currents the material removal rates of furnace cooled brass electrode is more than air cooled brass electrode (Figure 6).

At low and medium peak currents the electrode wear rate of furnace cooled brass electrode is slightly less than air cooled brass electrode. And at high peak currents the electrode wear rate of air cooled and furnace cooled brass electrode are almost same. From above graphical analysis the air cooled copper electrode is more suitable than furnace cooled electrode for machining in EDM. And the air cooled brass electrode and furnace cooled brass electrode are equally suitable for machining in EDM.

So from production point of view the air cooled brass electrodes are better than furnace cooled brass electrodes as they have higher material removal rates and produces more depth of cut even if the electrode wear rate of air cooled brass electrode is more than furnace cooled brass electrode (Figure 7).

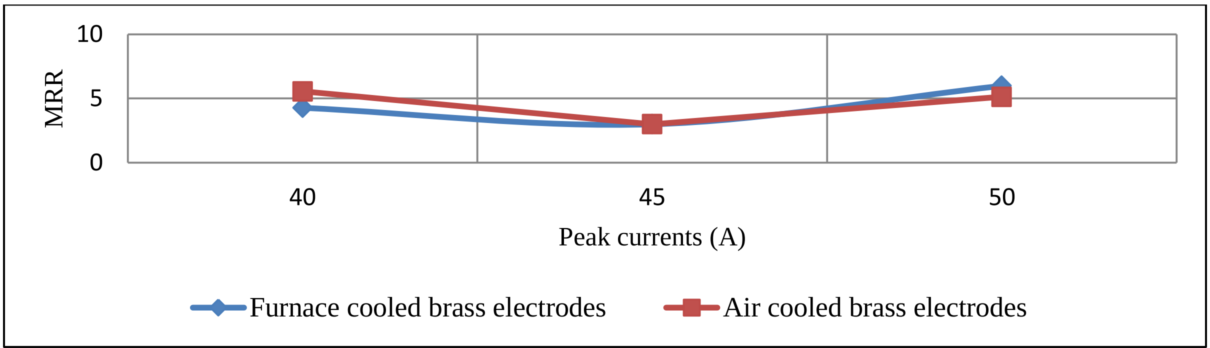

***Fig. 6**: Peak Current vs. MRR of Air Cooled and Furnace Cooled Brass Electrodes.*

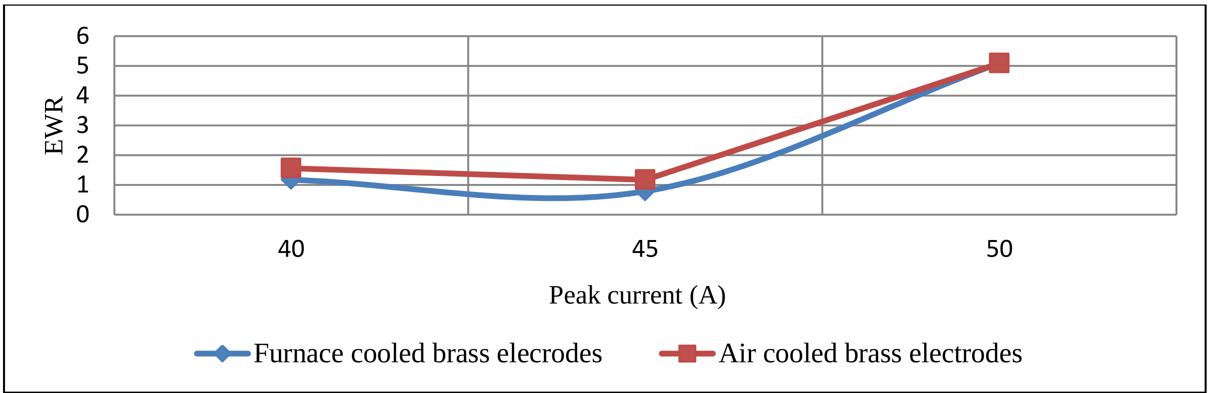

***Fig. 7:** Peak Current vs. EWR of Air Cooled and Furnace Cooled Brass Electrodes.*

Graphical Comparison Between Copper and Brass Electrodes

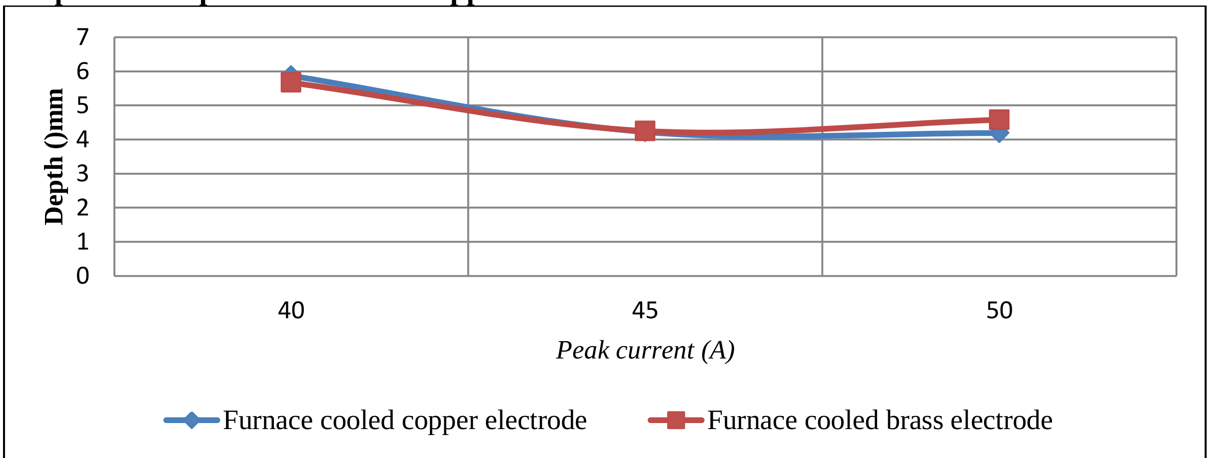

***Fig. 8:** Peak Current vs. Depth of Furnace Copper and Brass Electrodes.*

At low and medium peak currents the depth of cut produced by furnace cooled copper and brass electrodes are almost same. But at high peak currents the depth of cut produced by furnace cooled brass electrode is slightly more than that of furnace cooled copper electrode (Figure 8).

At low and high peak currents the material removal rates of furnace cooled copper electrode is slightly more than furnace cooled brass electrode. But at medium peak currents the material removal rates of furnace cooled copper and brass electrodes are almost same (Figure 9). At low and high peak currents the electrode wear rate of furnace cooled brass electrode is more than of furnace cooled copper electrode. And at medium peak currents the electrode wear rate of furnace cooled copper and brass electrodes are almost same. So even if the depth of cut produced by furnace cooled copper and brass electrode are same. But the material removal rates of furnace cooled copper electrode are more than furnace cooled brass electrode. And also the electrode wear rates of furnace cooled brass electrode are more than that of furnace cooled copper electrode. So furnace cooled copper electrode is more suitable than furnace cooled brass for machining in EDM (Figure 10).

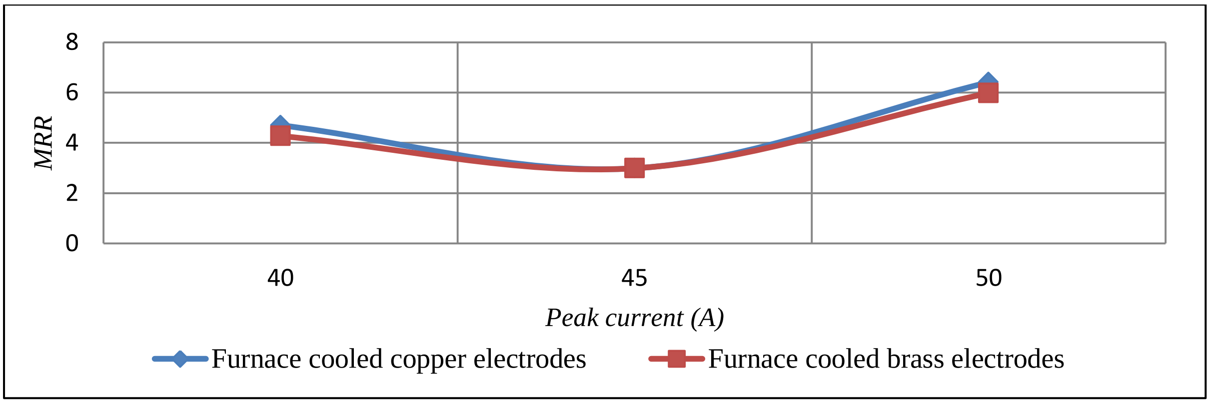

Fig. 9: *Peak Current vs. MRR of Furnace Cooled Copper and Brass Electrodes.*

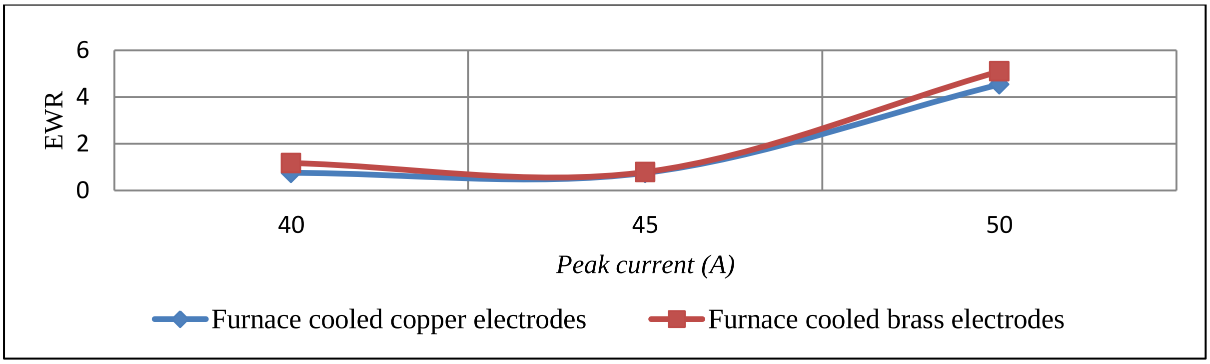

Fig. 10: *Peak Current vs. EWR of Furnace Cooled Copper and Brass Electrodes.*

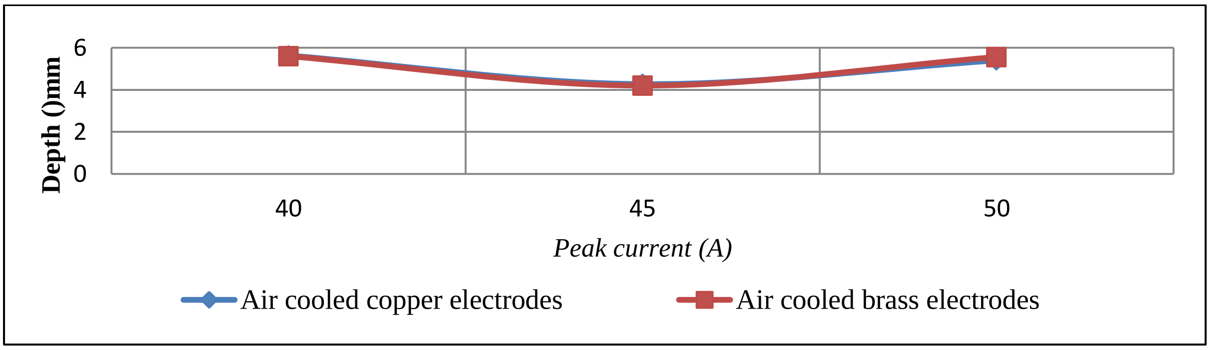

Fig. 11: *Peak Current vs. Depth of Air Cooled Copper and Brass Electrodes.*

At low, medium and high peak currents the depth of cut produced by both air cooled copper and brass electrodes are almost same (Figure 11).

At low, medium and high peak currents the material removal rates of air cooled copper electrode is slightly more than that of air cooled brass electrode (Figure 12).

At low peak currents the electrode wear rates of the air cooled brass electrodes is slightly more than air cooled copper electrodes. And at medium and high peak currents the electrode wear rates of air cooled brass electrodes is more than air cooled copper electrodes. Although depth of cuts produced by air cooled copper and brass electrodes are same. But the material removal rates of air cooled copper electrode are more than air cooled brass electrode. And also the electrode wear rate of air cooled brass electrode is more than air cooled brass electrode. So air cooled copper electrode is more suitable than air cooled brass electrode for machining in EDM. So it can be concluded that copper electrodes are suitable for machining with EDM in comparison to brass electrodes as copper electrodes have higher material removal rates and have higher depth of cuts and also the brass electrodes have higher electrode wear rates in comparison to copper electrodes (Figure 13).

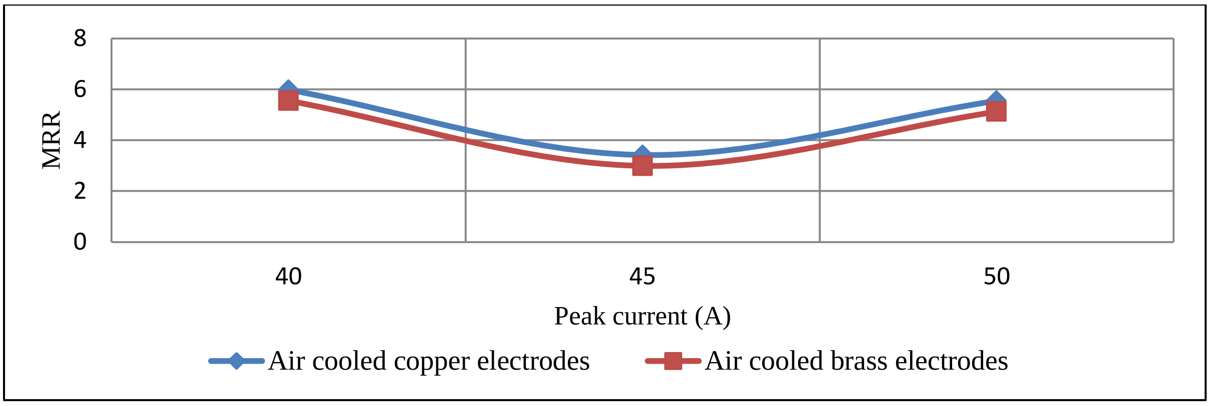

Fig. 12: *Peak Current vs. MRR of Air Cooled Copper and Brass Electrodes.*

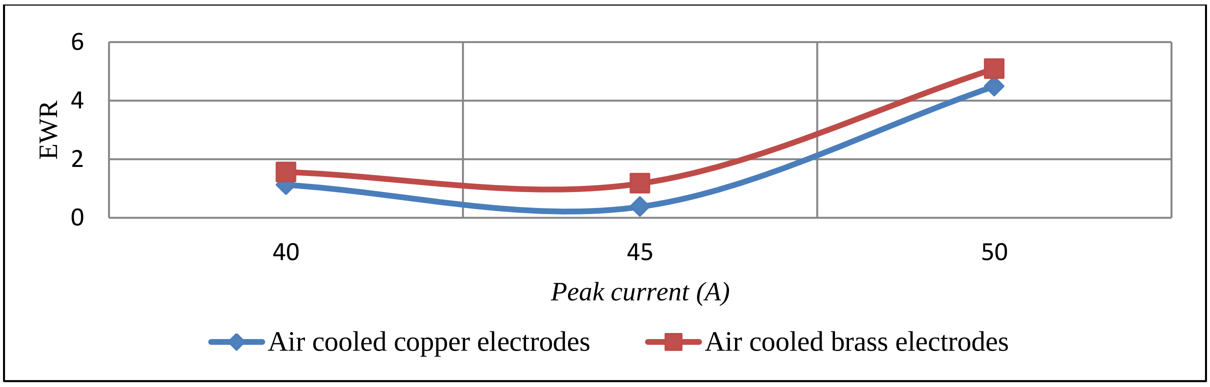

Fig. 13: *Peak Current vs. EWR of Air Cooled Copper and Brass Electrodes*

CONCLUSION

- The air cooled copper electrode is more suitable than air cooled brass electrode for machining in EDM as air cooled copper electrodes have higher material removal rates in comparison to air cooled brass electrodes and also the air cooled brass electrodes have higher electrode wear rate in comparison to air cooled copper electrode.
- The furnace cooled copper electrode is more suitable than furnace cooled brass electrode for machining in EDM as depth of cut and material removal rates of furnace cooled copper electrodes is slightly higher than furnace cooled brass electrodes and also the electrode wear rate of furnace cooled brass electrode is slightly more than furnace cooled copper electrode.

- The air cooled copper electrode is more suitable than furnace cooled copper electrode for machining in EDM as depth of cuts and material removal rates of air cooled copper electrode are higher in comparison to furnace cooled copper electrodes and electrode wear rate rates of both air cooled and furnace cooled copper electrodes are almost same.
- The air cooled and furnace cooled brass electrode are equally suitable for machining in EDM as depth of cuts and material removal rates are higher than those of furnace cooled brass electrode which is more favorable from production point of view even if electrode wear rate of air cooled brass electrode is more than those of furnace cooled copper electrode.
- Brass electrode is hard than copper electrode as Vickers hardness number of brass electrode is more than that of copper electrode.
- For brass electrodes the height and the weight of the electrodes increase for a given area of cross-section because brass is an alloy and liquid phase sintering occurring with brass material which has increases the sintered density of the electrode and thus its weighs more.
- For copper electrodes although height increases but the weight of the electrode decreases for a given area of cross-section due to solid phase sintering occurring with copper electrode which has reduces the sintered density of the electrode and thus the reduced weight.
- From production point of view the electrodes fabricated by powder metallurgy technique is more economical than electrodes which are manufactured by other manufacturing processes.
- For production of relatively complex parts, inner cavities and stepped cavities of high strength and hard alloys generally powder metallurgy technique is employed over other manufacturing methods.
- Powder metallurgy technique improves the physical, mechanical, chemical, thermal and electrical properties of the properties of products in comparison to other manufacturing process.

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