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Experimental investigation of EDM using Electrode Materials Copper, Brass and Chromium Copper for alloy steels

B.Venkatesh[1], Naveen.P [2], Maurya.B [3], Shanthi Priya.D [4]

[1] *Asst. Professor, Mechanical Engineering Dept, B.V.R.I.T, Narsapur, T.S, India*

[2, 3, 4] *B.Tech students, Mechanical Engineering Dept,*

B.V.Raju Institute of Technology, Narsapur, Telangana State, India.

Abstract — *Electrical Discharge Machining (commonly known as "EDM") is an unconventional machining method which is typically used for difficult to cut materials. In this process, the material removal takes place electro thermally by a series of consecutive discrete discharges between electrode and the work piece separated by a small gap which is dipped in a dielectric fluid. The spark is generated between tool and workpiece by the controlled pulsing of direct current. The present work has been under taken to study the effect of increase in pulsed current on material removal rate, electrode wear rate, and surface quality in alloy steels viz., EN 31, EN 8, HCHCr.The electrode materials viz. copper, brass, chromium copper are used to machine the alloy steels. Finally the main focus is find out best electrode material in order to achieve more efficient Material Removal Rate (MRR) coupled with reduction in Tool Wear Rate (TWR) and improved surface quality.*

Keywords- *EDM; Pulsed current; Alloy steels; Electrode materials; MRR; TWR; Surface roughness*

I. INTRODUCTION

Steel is one of the world's most essential materials. About 75% of the weight of typical household appliances comes from steel. Steel is found in appliances like fridges, washing machines, ovens, microwaves, sinks, cutlery etc. Steel also accounts of many industry goods like farm vehicles and machinery, storage tanks, tools, structures, walkways, protective equipment. The main reason for Steel standardization is to ensure a common language between producers and customers of steel products. Steel standards are used worldwide in many projects to determine steel type, strength, and properties. The European Committee for Standardization (CEN) is officially recognized as a European standards body by the European Union. The creation of the EEC (European Economic Community) has made it necessary to establish common standards named "European Norms" (EN), therefore standardizing the common language across Europe. Since 1988 a new series of 'mandatory' European standards (EN) has been created, to replace national standards, such as BS, DIN, SS and NF, throughout 18 countries of Western Europe. As per purpose, use, composition the examples of EN steels are EN31, EN8, EN9, EN24 etc. EN31 is a high carbon Alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. EN8 is a very popular grade of through-hardening medium carbon steel, which is readily machinable in any condition. EN8 is suitable for the manufacture of parts such as general-purpose axles and shafts, gears, bolts and studs [1, 2].

There are also D-grade steels as per AISI (UNS) standards namely D2, D3, D4, D5 etc.In this D3 is a high carbon-high chromium steel developed for applications requiring high resistance to wear or to abrasion and for resistance to heavy pressure rather than to sudden shock. Because of these qualities and its non-deforming properties, D3 is unsurpassed for die work on long production runs. This steel is used for manufacturing press tools, dies, die-casting, and sheering blades, both basic application exhibits some limitation due the abrasion phenomenon [2].

Electrical discharge machining (EDM) is a unconventional machining concept which has been extensively used to produce dies and molds. It is also used for finishing parts in aerospace and automotive industries [3].In this process the material is removed by successive electrical discharges between electrode and work piece which is dipped in a dielectric fluid medium. EDM has capacity to produce complex shapes on difficult-to-cut especially hard materials. However, the review presented in this paper is on the effect of increase in pulsed current on material removal rate, electrode wear rate, and surface quality in alloy steels viz., EN 31, EN 8, HCHCr.The electrode materials viz. copper, brass, chromium copper are used to machine the alloy steels.

II. LITERATURE REVIEW

The literature review which is related to EDM explains that surface quality of the machined component by EDM usually depends upon the preferred electrical parameters. There are many process parameters which affect the surface integrity such as pulse duration, material properties of tool electrode, workpiece, dielectric fluid and also size of the electrode [4]. These variables have great effect on mechanical properties of the material such as fatigue, hardness, corrosion and wear resistance [5]. Zang *et al*. had done investigation by preferring AISI 1045 steel as workpiece and copper as tool electrode which implied that the surface roughness of finished surface increases with increase in voltage, current and pulse duration [6].Khan *et al*. [7] discuss the performance about the shape configuration of the electrode. The maximum MRR was found for round electrodes followed by square, triangular and diamond shaped electrodes. However, the highest EWR were found for the diamond shaped electrodes. Subsequently, Khan [8] reported overall performance comparison of copper and brass electrodes and observed that the highest MRR was observed during machining of aluminium using brass electrodes. Comparatively low thermal conductivity of brass as an electrode material does not allow the absorption of much heat energy, and most of the heat is utilized in the removal of material from aluminium workpiece at a low melting point but more wear occurred than copper. Copper has high melting point and conductivity than brass. Dvivedi *et al*. [9] identified the machining performance in terms of MRR and TWR by obtaining an optimal setting of process parameters (T_{on}, T_{off}, I_p, and f_p) during EDM of Al6063 SiC_p metal matrix composite. It was revealed that I_p is predominant on MRR than other significant parameters. MRR increases with increasing I_p and T_{on} up to an optimal point and then dropped. Chiang [10] had explained the influences of I_p, T_{on}, Tau and voltage on the responses; MRR and electrodes wear and surface roughness. Jahan *et al*. investigated micro-EDM of tungsten carbide using different electrode materials of tungsten, copper tungsten and silver tungsten electrodes are capable of producing smooth and shiny surfaces with negligible amount of surface defects [11].

From the previous researches, it has been noticed that no considerable work has been carried out to study the effect of pulse current using copper, brass, and chromium copper electrode materials on the alloy steels viz., EN 31, EN 8, HCHCr. Therefore, this investigation is made to find out the effect of various electrode materials and pulse current on material removal rate, electrode wear rate and surface roughness in EDM of alloy steels (EN 31, EN 8, and HCHCr).The above mentioned materials have been selected based on wide range of applications in Automobile industries and general engineering works. Finally the main objective of this experimentation is to identify better electrode material whose outcome is to have greater MRR and lower EWR, with lower surface roughness and good dimensional accuracy.

III. MATERIALS AND METHODS

3.1 Machine tool

The equipment used to perform the experiments is an Electrical Discharge Machine (EXCETEK) shown in Fig 1.1. Commercial grade EDM oil (specific gravity = 0.763, freezing point= 94°C) is used as dielectric fluid. An impulse flushing system is employed for effective flushing of machining debris from the working gap region. However, the conductivity of the samples is enough to facilitate electrical discharge machining on samples because the machining process needs minimum conductivity of work piece as 0.01 S/cm [12].

Figure .1.1 Electrical Discharge Machine

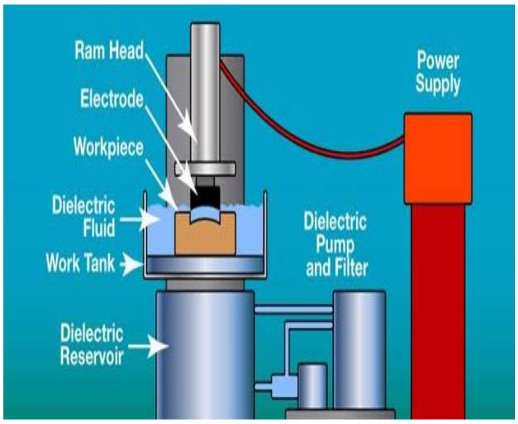


Figure .1.2 EDM complete system view

3.2 Work Piece Material

The work piece materials selected in the experimentation are EN 31, EN 8, and HCHCr. The chemical composition of the work materials are given in Table 1. The dimensions of the work piece material in length are 100 mm X 100 mm X 10 mm as shown in the Fig 1.3

	C	Mn	Si	S	P	Cr	Ni	Mo	Fe
EN 31	0.90 -1.20	0.30 - 0.75	0.10 - 0.35	0.040	0.040	1.00 - 1.60			Balance
EN 8	0.35 - 0.45	0.60 - 1.00	0.10 - 0.35	0.050	0.050				Balance
HCHCr	2.00 – 2.35	0.60	0.60	0.030	0.030	11.00-13.50	0.30		Balance

Table 1. Chemical composition (wt %) of work materials

EN 31 ***EN 8*** ***HCHCr***

Figure 1.3 Workpiece materials before machining

3.3 Electrode material

3.3.1 Copper

Due to the growth of pulse type power supplies copper has became the metallic electrode material of choice. The reason to choose copper is when it is combined with certain power supply settings low wear burning takes place. Copper can produce very fine surface finishes and has the capacity to remove large amounts of material [13]. This material is preferable for spark eroding cavities in Tungsten carbide particularly of small sizes and intricate shapes. For eroding all types of die cavities copper is advisable and its alloys like Chromium Copper, Copper Cadmium are also used for Electrode making.

3.3.2 Brass

Brass was one of the first EDM electrode materials. It is inexpensive and easy to machine. Today, however, brass is seldom used as an electrode material in modern sinker EDMs, due to its high wear rate. In certain applications or in older machines with RC power supplies for which wear is not a primary concern, brass still has limited use, since it exhibits a higher degree of stiffness and is easier to machine than copper. Brass, however, is one of the most commonly used materials for High Speed Small Hole Machines [13].

3.3.3 Chromium copper

Chromium copper electrodes are made of high copper alloys, containing 0.6 to 1.2% Cr. The chromium copper is used for their high strength, corrosion resistance and electrical conductivity. The chromium copper is age hardenable, which, in this case, means that a change in properties occurs at elevated temperature due to the precipitation of chromium out of the solid solution. The strength of fully aged chromium copper is nearly twice that of pure copper and its conductivity remains high at 85% as that of pure copper. These high strength alloys retain their strength at elevated temperatures. The corrosion resistance of chromium copper alloys is better than that of pure copper because chromium improves the chemical properties of the protective oxide film. Chromium copper has excellent cold formability and good hot workability.

A: Brass Electrode ***B: Chromium Copper Electrode*** ***C: Copper Electrode***

Figure 1.4 Electrode materials used for machining

	Cu	Ag	Bi	O	P	Pb	Zn	Cr
Copper	99.90		0.0005	0.040		0.005		
Brass	85						15	
Chromium Copper	99.1							0.9

Table 2. Chemical composition (wt %) of electrode materials

3.4 Experimental Procedure

Due to evolution in the field of EDM processes, it has now become necessary to determine the best tool material for higher material removal rate, lower electrode wear rate and also with improved surface finish. The selection of electrode material depends mainly on the specific cutting application and the material being machined. The primary requirement of any electrode in EDM is that it should be electrically conductive and should maintain less electrode wear. Keeping this in mind the pulse current is normally selected on the basis of the maximum removal rate possible within the allowable mean current, electrode wear and surface integrity. The experiments were carried out for a depth of cut of 2 mm for all electrode materials with four different pulse current settings of 6 A, 12 A, 18 A an 24 A . A cylindrical tool with a diameter of 15 mm is used for all tool electrodes to machine the workpiece. During this process pulse current was raised by keeping the voltage at 40 V, pulse duration at 25 µs, pulse interval at 200 µs and dielectric fluid pressure at 20 kPa for all machining conditions. The polarity of electrode materials Copper, Brass, Chromium Copper was negative [14].The photos of machined alloy steels (EN 31, EN 8, HCHCr) with different electrode materials are shown in the fig 1.5.There are many ways of measuring MRR and TWR, in this experimentation the material removal rate (MRR) and tool wear rate (TWR) values have been calculated by difference in weight of work material and electrode before machining and after machining time using electronic balance weight measuring machine. The formula for calculating MRR is stated in the equation (1)

$$MRR = \frac{W_i - W_f}{\rho_w T} \qquad (1)$$

Where W_i and W_f are intial and final weight of work piece before and after machining, ρ_w is density of work piece material and T is the machining time. Tool wear rate is expressed as where T_i and T_f are the intial and final weight of tool before and after machining, ρ_t is density of tool material and T is the machining time. The formula for calculating TWR is stated in equation (2)

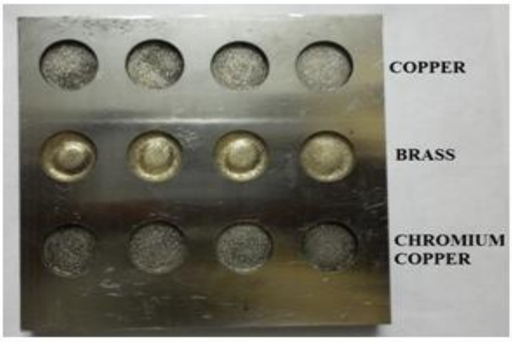
$$TWR = \frac{T_i - T_f}{\rho_t T} \qquad (2)$$

The density values of work piece materials EN31, EN8, HCHCr and tool material Copper, Brass, Copper Chromium were used to calculate MRR and TWR

Work piece material	Density (gm/mm^3)
EN 31	0.00785
EN 8	0.00795
HCHCr	0.00770

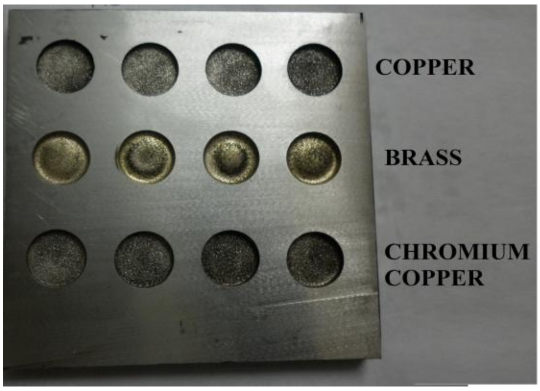
Tool material	Density (gm/mm^3)
Copper	0.00894
Brass	0.00870
Copper Chromium	0.00805

Table 3. Density values of tool material and workpiece material



(a) EN 8

(b) EN 31



(c) HCHCr

Figure 1.5 Machined alloy steels using EDM

IV. RESULTS AND DISCUSSION

4.1 Results of EN31 with different electrodes

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	139.18	139.15	769	767	34	0.10	7.49	7.2
12	139.15	139.14	767	766	9	0.12	14.15	9
18	139.14	139	766	763	6	2.61	63.69	13.6
24	139	138.93	763	759	5	1.57	101.91	12.6

Table 4. Tool wear rate, Material removal rate and Surface roughness values of EN31 with copper electrode

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	129.55	127	759	757	53	5.53	4.81	5.1
12	127	124.67	757	754	17	15.75	22.48	7
18	124.67	121.55	754	752	15	23.91	16.99	7.8
24	121.55	118.21	752	750	22	17.45	11.58	9

Table 5. Tool wear rate, Material removal rate and Surface roughness values of EN31 with brass electrode

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	221.47	221.45	750	746	34	0.07	14.99	7.4
12	221.45	221.44	746	743	11	0.11	34.74	10.4
18	221.44	221.39	743	739	7	0.89	72.79	11.8
24	221.39	221.36	739	734	6	0.62	106.16	12

Table 6. Tool wear rate, Material removal rate and Surface roughness values of EN31 with Chromium copper electrode

4.1.1 Effect of pulse current on Material Removal Rate of EN31

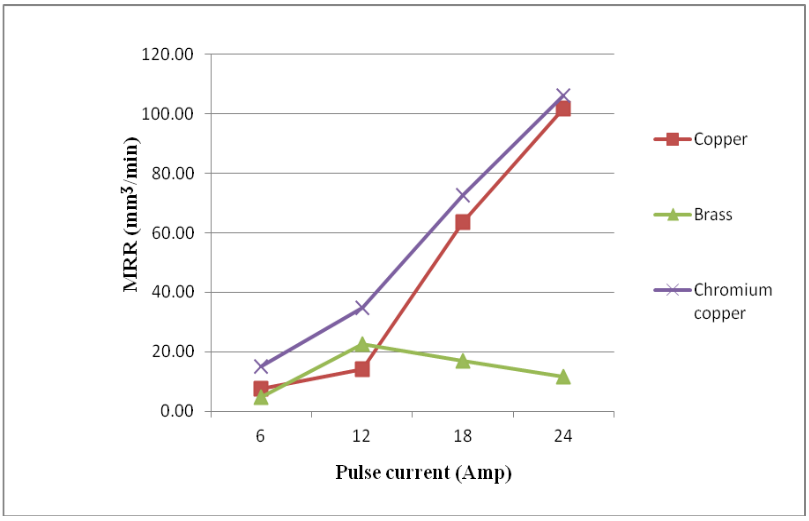


Figure 1.6 Effect of pulse current on material removal rate of EN31

Fig 1.6 shows the effect of pulse current on MRR of EN31 work material. The trend shows that as the pulse current increases, the MRR also increases and similar trend has been observed for the two electrode materials except brass with improper machining. The chromium copper electrode yields the highest MRR of 106.16 mm^3/min followed by copper of 101.91. mm^3/min and brass of 22.48 mm^3/min for EN31 steel. The increase in MRR with the increase in pulse current is due to the enhancement of spark energy that facilitates the action of melting and vaporization. More so, this action results in advancing the impulsive force in the spark gap and thereby increasing the MRR.

4.1.2. Effect of Pulse Current on Tool Wear Rate of EN31

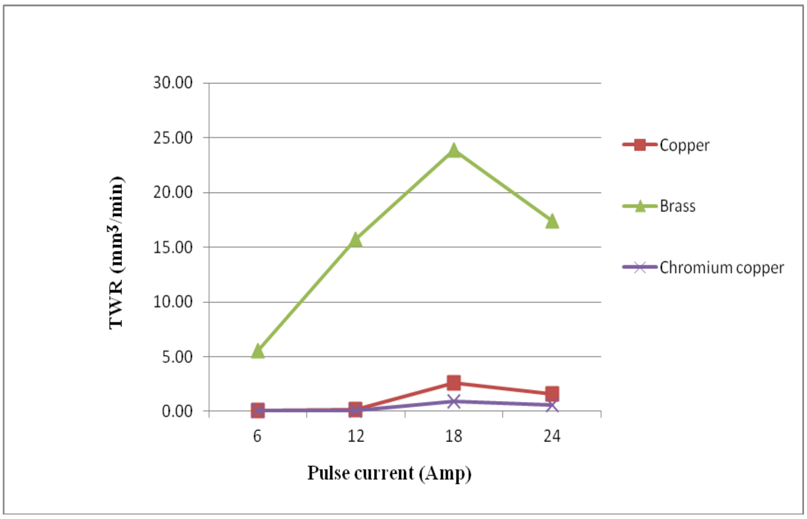


Figure 1.7 Effect of pulse current on tool wear rate of EN31

Electrode wear is mainly due to high density electron impingement generated during machining from work and electrode materials. The graph between tool wear rate vs. pulse current for EN31 material is shown in Fig 1.7. Brass has the highest tool wear rate of 23.91 mm^3/min as against 0.07 mm^3/min for Chromium copper and 0.10 mm^3/min for copper. In brass electrode, the TWR increases as the pulse current is increased due to its low melting point where as in copper and Chromium copper the TWR is less because of their high melting point. For all the three electrode materials, it shows that the trend of TWR graph remains relatively constant after about 18 A. The TWR of Chromium copper is very low when compared with other two electrode materials because of high resistance spark.

4.1.3 Effect of Pulse Current on Surface Roughness of EN31

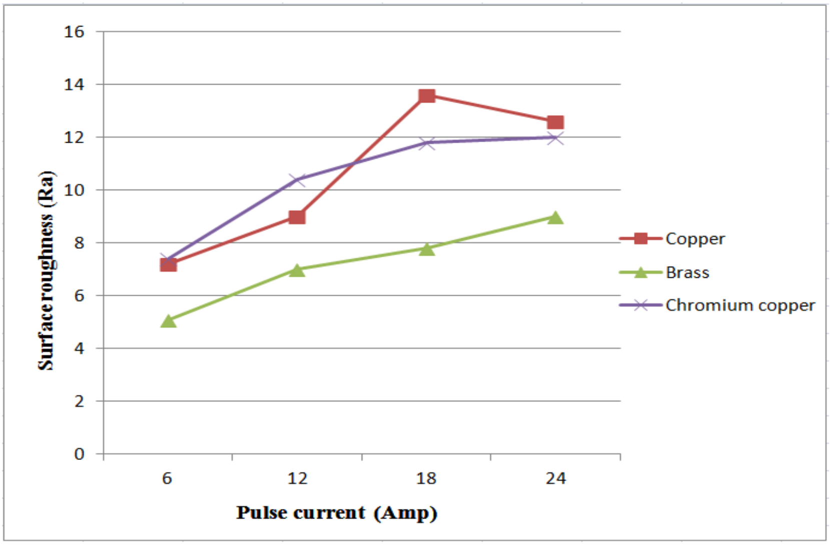


Figure 1.8 Effect of pulse current on surface roughness of EN31

Fig 1.8 shows the effect of pulse current on the surface roughness of the work material EN 31 respectively. It has been observed that as the pulse current is increased the surface roughness increases. The results of the above mentioned work material EN31 indicate that for the range of pulse current used *i.e.*, between 6 A and 24 A, brass exhibits better surface finish with poor machining and dimensional accuracy but when comparison is done for Copper and Chromium copper which has a good dimensional accuracy it is found that Chromium copper has low surface roughness and the value increases with increase in pulse current where as copper gives low surface roughness values at the pulse current of 6 A, 12A and 24 A. If we compare copper and Chromium copper electrode it has been observed that the surface roughness are high due to the fact that higher MRR accompanied by larger and deeper craters. This causes low pulse currents and spark energy which leads to the formation of small craters on the machined surface and thereby improving surface finish. Therefore, formation of small craters results in good surface finish.

4.2. Results of EN8 with different electrodes

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	139	139	795	791	23	0.00	21.88	9
12	139	139	791	788	10	0.00	37.74	9.4
18	139	138.88	788	785	7	1.92	53.91	10.2
24	138.88	138.62	785	782	5	5.82	75.47	10.8

Table 7. Tool wear rate, Material removal rate and Surface roughness values of EN8 with copper electrode

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	118.21	115	781	778	66	5.59	5.72	6.47
12	115	111.89	778	776	24	14.89	10.48	7.2
18	111.89	108	776	774	22	20.32	11.44	7.9
24	108	103	774	772	20	28.74	12.58	8.4

Table 8. Tool wear rate, Material removal rate and Surface roughness values of EN8 with brass electrode

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	221.32	221.25	772	768	15	0.58	33.54	8
12	221.25	221.17	768	765	8	1.24	47.17	9.8
18	221.17	221.06	765	761	8	1.71	62.89	11.2
24	221.06	221	761	756	7	1.06	89.85	12.6

Table 9. Tool wear rate, Material removal rate and Surface roughness values of EN8 with chromium copper electrode

4.2.1 Effect of pulse current on Material Removal Rate of EN31

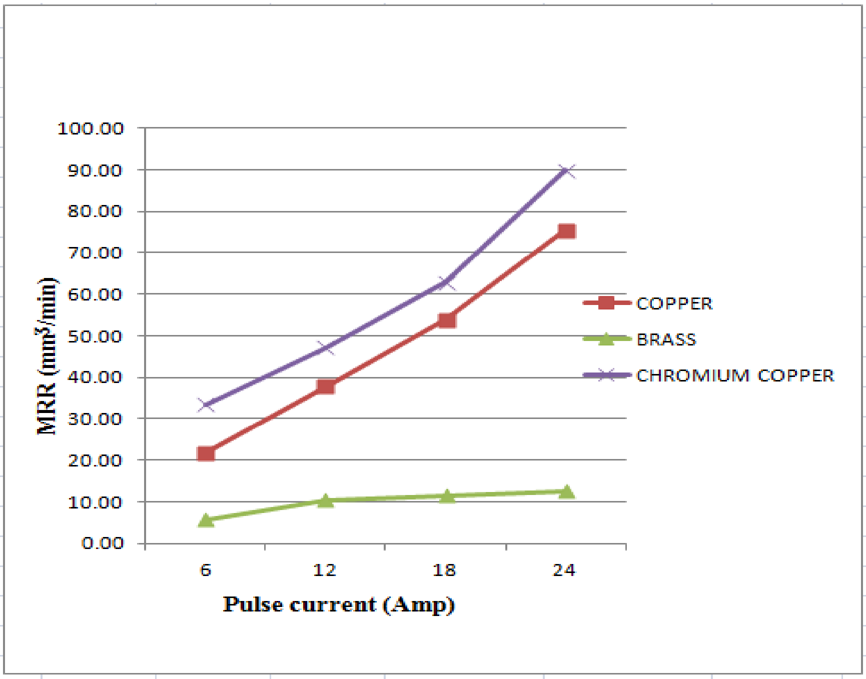


Figure 1.9. Effect of pulse current on material removal rate of EN8

From the Fig.1.9 shows the effect of discharge current on MRR for EN8 workpiece material. It is been observed that in case of Chromium copper electrode the MRR increases with increase in the discharge current has highest material removal rate (75.47 mm^3/min) of with increase in pulse current for EN8.The copper electrode produces moderate increase in MRR with increase in discharge current, whereas at the brass electrode does not produce any significant increase in the MRR (12.58 mm^3/min) due to increase in the discharge current. So due to effect of pulse current on EN8 material Chromium copper has highest material removal rate because of chromium content in copper that makes the electrode heat resistant and perform at increase in pulse current.

4.2.2 Effect of pulse current on tool wear rate of EN8

Figure 1.10 depicts the effect of pulse current on the tool wear of the work piece material EN8. It has been observed that Brass has highest TWR as against for copper and Chromium copper. In brass TWR increases with increase in pulse current to its low melting point where as in copper and chromium copper the TWR is less because of their high melting point. For all the three electrodes it shows that the trend of TWR graph remains relatively constant after about 24 A. The TWR of Chromium copper is very low when compared with other two electrode materials because of high resistance to spark.

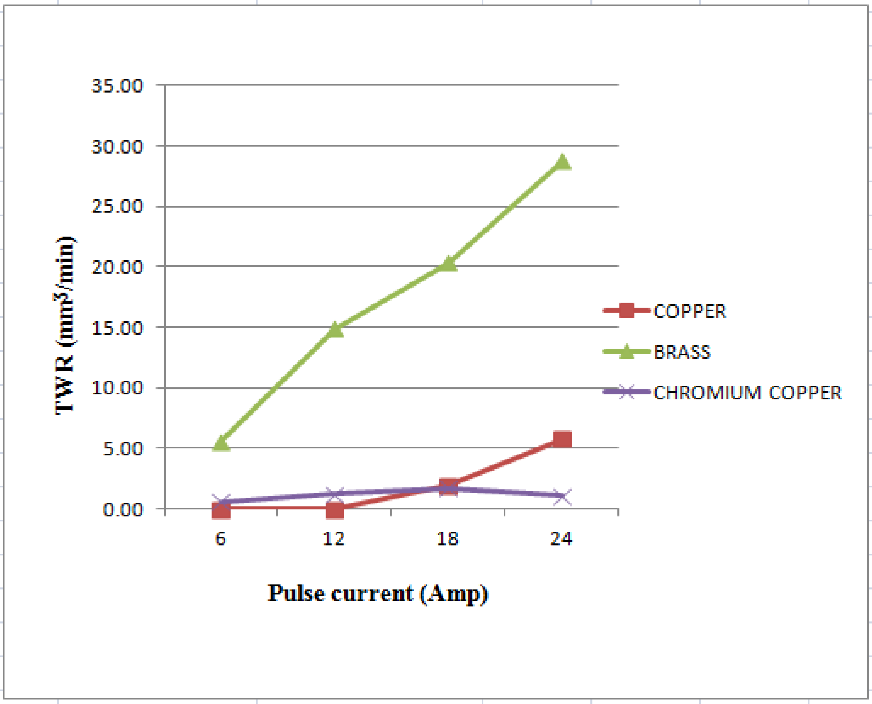


Figure 1.10 Effect of pulse current on tool wear rate of EN8

4.2.3 Effect of pulse current on surface roughness of EN8

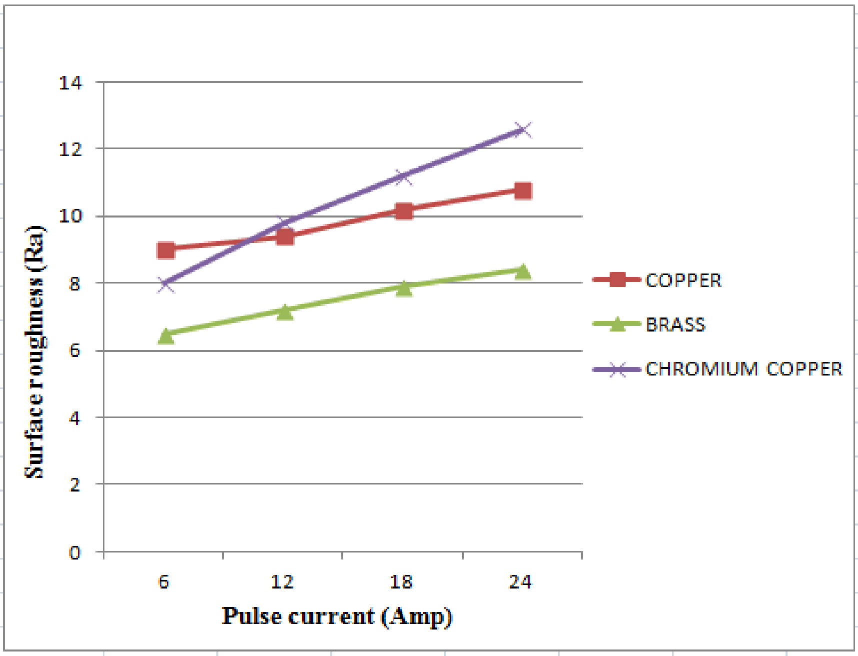


Figure 1.11 Effect of pulse current on surface roughness of EN8

Figure 1.11 shows the effect of pulse current on surface roughness of EN8 and it has been observed that as the pulse current is increased the surface roughness increased. The results of the above mentioned workpiece material indicate the range of pulse current used i.e. between 6 A and 24 A, brass exhibits better surface roughness with improper dimensional accuracy where as for copper and chromium copper, copper produces lower surface roughness compared to that of chromium copper. The surface roughness of copper and chromium copper are high due to the fact that higher MRR is accompanied by larger and deeper craters. Therefore formation of small craters results in good surface finish.

4.3 Results of HCHCr with different electrodes

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	138.86	138.84	818	815	19	0.12	20.51	7.8
12	138.84	138.83	815	813	10	0.11	25.97	10.9
18	138.83	138.81	813	809	8	0.28	64.94	10.4
24	138.81	138.76	809	804	7	0.80	92.76	10.6

Table 10. Tool wear rate, Material removal rate and Surface roughness values of HCHCr with copper electrode

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	103	98.46	805	802	55	9.49	7.08	4.2
12	98.46	93.57	802	800	31	18.13	8.38	7.4
18	93.57	89	800	797	22	23.88	17.71	8.6
24	89	83.5	797	795	17	37.19	15.28	9.1

Table 11. Tool wear rate, Material removal rate and Surface roughness values of HCHCr with brass electrode

Current (A)	Initial weight of tool (gm)	Final weight of tool (gm)	Initial weight of Work piece (gm)	Final weight of work piece (gm)	Time (min)	TWR (mm^3/min)	MRR (mm^3/min)	Surface Roughness (R_a)
6	221	221	795	792	30	0.00	12.99	9.6
12	221	221	792	789	19	0.00	20.51	9.8
18	221	221	789	785	8	0.00	64.94	10.6
24	221	220.89	785	781	7	1.95	74.21	10.4

Table 12. Tool wear rate, Material removal rate and Surface roughness values of HCHCr with Chromium Copper electrode

4.3.1 Effect of pulse current on material removal rate of HCHCr

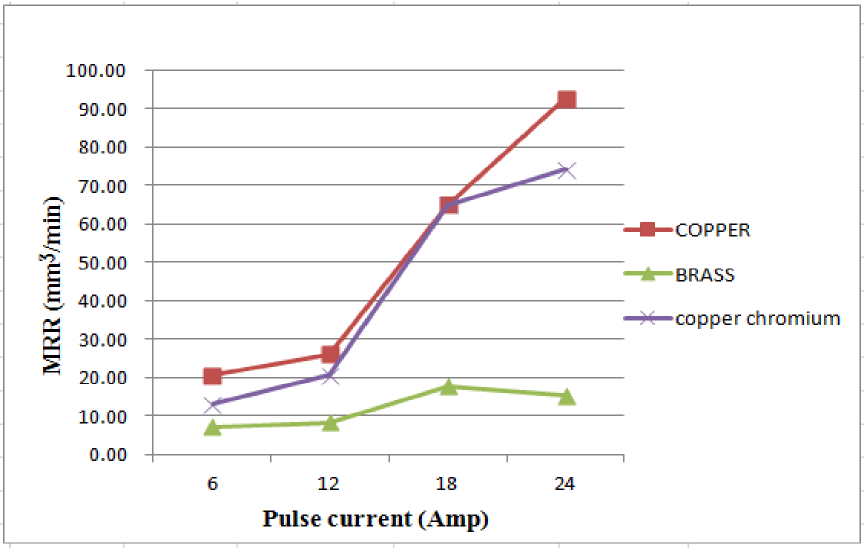


Figure 1.12.Effect of pulse current on material removal rate of HCHCr

Fig 1.12 shows the effect of pulse current on MRR of HCHCr work material. The trend shows that as the pulse current increases, the MRR also increases and similar trend has been observed for the two electrode materials except brass with improper machining. The copper electrode yields the highest MRR of 92.76 mm^3/min followed by Chromium copper of 74.21. mm^3/min and brass of 17.71 mm^3/min for EN31 steel. The increase in MRR with the increase in pulse current is due to the enhancement of spark energy that facilitates the action of melting and vaporization. More so, this action results in advancing the impulsive force in the spark gap and thereby increasing the MRR.

4.3.2 Effect of pulse current on tool removal rate of HCHCr

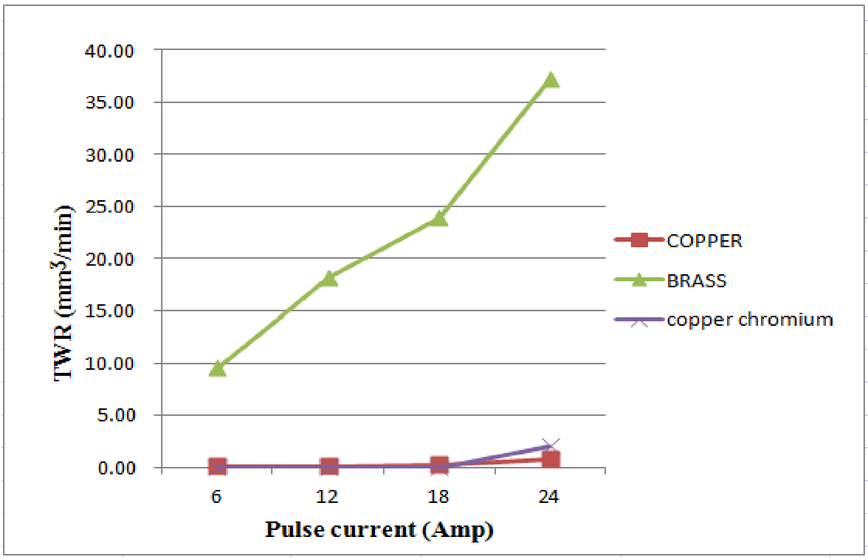


Figure 1.13 Effect of pulse current on tool wear rate of HCHCr

Figure 1.13 depicts the effect of pulse current on the tool wear of the work piece material HCHCr. It has been observed that Brass has highest TWR on HCHCr as against for copper and Chromium copper. In brass TWR increases with increase in pulse current to its low melting point where as in copper and chromium copper the TWR is almost negligible because of their high melting point. For all the three electrodes it shows that the trend of TWR graph remains relatively constant after about 24 A. The TWR of copper is very low when compared with other two electrode materials because of high resistance to spark.

4.3.3 Effect of pulse current on surface roughness of HCHCr

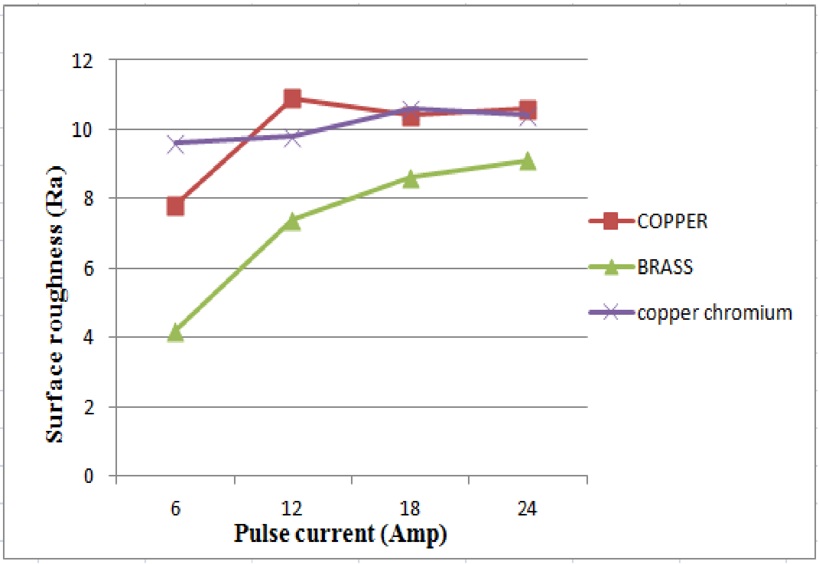


Figure 1.14 Effect of pulse current on surface roughness of HCHCr

Figure 1.14 shows the effect of pulse current on surface roughness of HCHCr and it has been observed that as the pulse current is increased the surface roughness increased. The results of the above mentioned workpiece material indicate the range of pulse current used i.e. between 6 A and 24 A, brass exhibits better surface roughness with improper dimensional accuracy where as for copper and chromium copper, chromium copper produces lower surface roughness compared to that of copper. The surface roughness of copper and chromium copper are high due to the fact that higher MRR is accompanied by larger and deeper craters. Therefore formation of small craters results in good surface finish.

V. CONCLUSION

From all the above detailed analysis of various performances of parameters of EDM process it has been concluded that

1. Chromium copper is found to be having the highest MRR, followed by Copper and Brass and also TWR of brass is very high followed by copper and Chromium copper which have least.
2. The tool and work piece surface roughness measured indicates that copper has highest surface roughness followed by Chromium copper and Brass. Therefore we can say that Brass has got good surface finish properties but due to formation of cavities, high TWR and low MRR, it's not favorable for EDM process.
3. Copper and Chromium copper electrodes performed persistently at high values of pulse current and Chromium copper offers good dimensional accuracy than copper.
4. Copper and Chromium copper is found to be almost similar so the electrode should be chosen based upon the parameters like MRR,TWR and R_a availability and cost
5. Surface roughness increases with increase in pulse current.
6. Chromium copper electrode has been preferred for highest material removal rate, dimensional accuracy and surface finish.

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