International Journal of General Engineering and Technology (IJGET)
ISSN: 2278-9928
Vol.1, Issue 2 Nov 2012 35-46
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International Academy of Science, Engineering and Technology
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COMPARATIVE ANALYSIS OF MILLING OF COPPER AND GRAPHITE ELECTRODES FOR EDM AND IDENTIFYING MACHINE CAPABILITIES

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ABSTRACT

Copper and graphite are the two mostly used materials in Electrical Discharge Machining electrodes in injection mould making. Though several research papers found on comparative analysis of copper and graphite milling, they are not applicable to the selected tool manufacturing company, since the machines used are different and it is totally applications-driven and so much depends on what you have to work with on the shop floor in the way of support equipment. In this work a tool (cost calculator) is developed to be used on the shop floor for a plastic injection mould manufacturing company for the comparative analysis of milling of copper and graphite electrodes for EDM. Machine capabilities of copper and graphite milling are analysed by experimental methods with the optimum parameters set in the machines. Material removal rate for rough milling and surface finishing rate for fine milling are found to be indicators of machine capabilities.

An experienced tool maker can use the cost calculator, providing necessary inputs to calculate the cost and time of producing electrodes, leads to a proper comparison of EDM electrode milling in economical terms rather than a guess, which is the current practice.With the use of the cost calculator the costs and time of producing electrodes are analysed and recommendations made based on the data available with EDM machines in general. Also flexibility is provided in the cost calculator to change the values fed in the calculator, so that it can be customized for the use of any other tool shop.

KEYWORDS: CNC Milling, Copper Electrodes, Cost Calculator,Graphite Electrodes, Machine Capabilities, Sinking EDM

INTRODUCTION

When it comes to Electrical Discharge Machining (EDM) electrode material, copper versus graphite debate has raged on for decades. Kern (2008) says that during the 1960s, copper was used nearly 90 percent of the time for metallic electrode materials, while graphite was used 10 percent of the time. However today, the numbers are reversed and more than 90 percent of the EDM electrodes being used are graphite. Hough (2011) argued why graphite becomes the best choice for EDM and Amorim (2007) shows the behaviour of graphite and copper in EDM. When it comes to decide whether to use graphite or copper electrodes in a shop, it is important to look at the wider picture. To say which electrode works best is very difficult, it is totally applications-driven. So much depends on what you have to work with on the shop floor in the way of support equipment. Because of the advantages, modern tool shops use both graphite and copper electrodes according to the requirement, but the decision is made by an experienced tool maker using his experience to judge what electrodes are required in making a compromise between the required surface finish to be achieved and the cost. Proper comparison in economical terms for the material used for EDM electrodes will make it easy in the final decision making.

One of the largest and foremost manufacturers of precision tools for injection moulding is selected to develop a tool to facilitate the comparative analysis of milling of copper and graphite electrodes for EDM. Tool manufacturing company has been using both graphite and copper electrodes for decades, but still it has not been analysed properly. With the available machinery it is decided to analyse the capabilities of milling of copper and graphite electrodes. Certain machines are recommended for one material where as some are capable of milling different materials. Under fully utilized condition of machines it is very important to know that the cost effectiveness of using graphite and copper electrodes in shop. Considering three mostly used machines in electrode milling with similar milling parameters, individual machine capabilities are found by calculating MRR and electrode finishing rate. It is expected to assist decision making in selecting EDM material and costing. Performance of copper and graphite in EDM has to be studied separately under different conditions to come to a final conclusion of the overall effectiveness of using graphite or copper. Results of EDM shown by Kern (2008) is used to conclude on the results.This study would lead to make a comparison of milling of copper and graphite electrodes in economical terms at the selected machines.Also this will re-evaluate the machines and set new standards for costing. Finally, data used would lead to create a cost calculator, which can be used to estimate the time and cost required in milling electrodes.

EXPERIMENTAL WORK

It was decided to select three machines which were used often and collect machining data from the on-going projects with the intention of finding MRR and the fine milling rate.When selecting samples for experiments it was noted that within a wide range of electrode sizes were selected and electrodes having extremely complicated shapes were avoided due to practical limitations. To handle the variations of MRR and fine milling rate the parameter complexity introduced and identified in three categories HI/MED/LOW (high/medium/low). Complexity was decided by using the experience; it depends on the surface complexity, milling strategy to be used and the amount of milling to be done.Volumes and finished surface areas were calculated using solid works. In calculating volumes there was an error due to the cusp exist in the electrode after milling. It would be noted that after finishing the electrode effect of cusp was negligible but it wasconsiderable afterroughing.By analysing the data copper and graphite milling machine capabilities were identified and cost calculator was developed.

Machines:	Röders RMS 6 machine- High speed machine for both copper and graphite	
	Hyper5 MAKINO V55 machine-Copper milling machine	
	SNC 64 machine-Graphite milling machine with excellent dust extractors	
Software	All CNC programs for milling were written using PowerMILL Pro 8.009 SP2	
	All volume and surface area calculations were done using solid works 2007/2010.	
Milling Tools	Diamond coated magaforceGraph'X 8529G K15 carbide) 8000HV	
	Tool life Grphite-Fine-8200 secs	Tool life Grphite-Rough-7200 secs
	Hard’X coating magaforceHard'X 8529H K15 carbide) 3000HV	
	Tool life copper-Rough-10000 secs	Tool life copper-Fine-9000 secs

Milling Parameters were set using expert systems, tool catalogues and trials.

Drozda (1998) shows how to select milling parameters in CNC milling,Cus (2007) and Gopala (2007) shows how to optimize milling parameters in CNC milling.Size of the electrode: Electrode block size was used as a measure of the electrode size. To cover a wide range of electrodes milled in the machines, 67 electrodes were selected, the range selected for graphite was 10000mm^3 -490000mm^3 which was about 96% of the electrodes milled in graphite. Sample electrodes were selected from the above range.

Most of the copper electrodes were small in size and machine capabilities showed it was not possible to use more than 6mm tools in copper milling. The size variation was minimal in copper. As a practice it is believed, by experience, copper rough milling is better with a tip radius tool. Therefore both tip radius and ball nose tools were selected in copper milling.

EXPERIMENTS AND DATA COLLECTED

- Considering the Mostly used tools in electrode milling it was decided to use 8mm 6mm and 4mm ball nose tools in each machine. Fine and rough milling data(milling times) were collected for each tool.
- Data (milling time) was collected for tools of diameter 3mm-0.5mm with few more experiments. Fine milling data were collected for each tool.
- Roy (2001) suggested how to select number of samples in an experiment. For rough milling two variable inputs block size and % reduction one out put MRR, four samples for each tool is selected for analysis.
- For graphite, Röders and SNC 64 were the dominant machines. For copper, Hyper5 and Röders were selected.
- Initial volume of the block was taken from the set up sheet.
- Final volume was calculated using solid works.
- Fine milled surface area was calculated using solid works.

STUDY OF MRR FOR ROUGH MILLING

Calculation of MRR

$$MRR = (V_i - V_f) / T_M \quad mm^3/sec$$

Here, V_i is the initial volume of the block. V_f is the volume of the CAD model.

T_M is the milling time. (Taken from machine)

CAD volume calculation in solid works

- Cad model is cut extruded in solid works below the rough milled area.
- Apply the necessary thickness left in milling by move surface command.
- Volume calculation command is applied to find the volume of the CAD model (V_f).

MRR is calculated for all three selected machines in both copper and graphite where applicable.

Calculation of reduction percentage

$$\text{Reduction \%} = (V_i - V_f) / V_i \quad \%$$

Table 1: Variation of MRR with Percentage Reduction and Initial Volume for Graphiteröders and SNC64 Machines

Electrode No	Tool Dia (mm)	Time (sec)	Block size (mm3)	Reduction (%)	MRR (mm3/sec)
11408b200	8	76	61250	71	571
11446b101	8	359	396480	55	604(L)
11408b201	8	88	61250	78	543(H)
11433b412	8	179	185976	55	568
11367s406	6	44	24150	59	274(H)
11368b201	6	65	34200	60	305
11408f100	6	190	116480	68	307(L)
11368b200	6	77	34200	70	300
11433f413	4	158	50400	54	174(H)
11433f410	4	82	18600	78	175
11433f406	4	90	25200	64	178(L)
11433b414	4	135	42120	57	177

Table 2: Rough Milling of Copper V55 Hyper 5 Machine

Electrode No	Tool Dia (mm)	Time (sec)	Block size (mm^3)	Reduction (%)	MRR (mm^3/sec)
11408r104	6Tip0.3	207	3600	37	6.48
11408r103	6Tip0.3	255	3600	49	6.93
11408r102	6Tip0.3	261	3600	50	6.93
11368r209	6Tip0.3	226	3375	47	6.89
11420r401	6Ball	186	2925	27	4.25
11362k02	6Ball	463	3375	58	4.25
11420r401	6Ball	246	2925	27	3.22
11397u400	6Ball	298	2250	52	3.93
11397u401	4Ball	399	2025	57	2.87
11405r05	4Ball	597	3600	37	2.26
11390b1502	4Ball	368	2250	54	3.3
11405r06	4Ball	649	3600	61	3.4

Table 3: Rough Milling of Röders Copper

Electrode No	Tool Dia (mm)	Time (sec)	Block size (mm3)	Reduction (%)	MRR (mm3/sec)
11408r104	6Tip0.3	287	3600	37	4.68
11408r103	6Tip0.3	353	3600	49	5.01
11408r102	6Tip0.3	362	3600	50	4.99
11368r209	6Tip0.3	388	3375	57	4.96
11362k02	6Ball	463	2925	58	4.25
11420r401	6Ball	246	2250	27	3.22

Table 3: Rough Milling of Röders Copper – Contd.

Electrode No	Tool Dia (mm)	Time (sec)	Block size (mm3)	Reduction (%)	MRR (mm3/sec)
11397u400	6Ball	298	2250	52	3.93
11367r411	6Ball	483	3375	70	4.88
11389k201	4Ball	363	3600	49	4.82
11389k200	4Ball	445	3600	49	3.96
11405r06	4Ball	649	3600	61	3.4
11390b1502	4Ball	368	2250	54	3.3

The criteria complexity is introduced to handle the variations observed in MRR and Table 1 shows how the electrodes are categorized as: HIGH (H) and LOW (L) complex electrodes. This classification was done using MRR variation with the block size and reduction % considering the complexity of the model.Same method is used for copper milling

MRR variation is low in copper. Therefore average MRR is taken for each tool

$$\text{Average MRR} = \Sigma\ MRR_i / (N)$$

$$\text{Here } i = 1, 2 \ldots\ldots N$$

MRR for Hyper5 and Roders machine was calculated

ANALYSIS OF FINE MILLING

The ability of graphite fine milling was determined by the observation of the fine milled surface and the rate of fine milling. Area finished by a tool was measured by calculating the relevant surface area by solid works. Whenever different tools were used in milling respective area done by a tool was calculated separately. Milling time of the tool was taken from the machine data for the final calculation of the rate of fine milling.

Calculations done by solid works,

- Electrode was cut extruded below the milled level and the relevant thickness applied using Face Move command.
- The surface area was calculated using area calculation command.
- Subtract any area not milled and calculate the actually milled surface area.
- If small tool was used to reduce a corner radius, area finished by the small tool was separately calculated by splitting the surface applying area calculation command.

$$R_f = A_f / T_M \quad mm^2/sec$$

Here, R_f is rate of fine milling mm^2/sec

A_f is fine milled surface area mm^2

T_M is time taken for milling sec

R_f was identified in three categories. It was observed that when the complexity increases R_f decreases, so the complexity of electrode was identified as a factor to consider when deciding rate of milling and divided into HIGH, MEDIUM and LOW. Complexity depends on surface complexity, milling strategy to be used. Samples selected in above three categories.

Variation of fine milling rate for copper and graphite for all three machines are calculated in the same way

Average R_f $= \Sigma R_f / (N)$ Here, $i = 1, 2 \ldots\ldots N$

Table 4: Variation of R_f with Tool Diameter

Tool Dia (mm)	Röders Graphite (mm2/sec)	SNC64 Graphite (mm2/sec)	Röders Copper (mm2/sec)	Hyper5 Copper (mm2/sec)
8Ball	8.0(H) 7.5(M) 7.1(L)	6.2(H) 5.4(M) 4.7(L)	-	-
6 Ball	5.6(H) 5.3(M) 5.0(L)	4.6(H) 4.5(M) 4.3(L)	3.5(H) 3.2(M) 2.9(L)	4.1(H) 3.9(M) 3.8(L)
4Ball	5.6(H) 5.3(M) 5.0(L)	4.6(H) 4.4(M) 4.2(L)	4.6(H) 4.3(M) 4.1(L)	4.1(H) 3.8(M) 3.6(L)
2Ball	1.7(H) 1.5(M) 1.4(L)	2.5(H) 2.3(M) 2.2(L)	3.5(H) 2.4(M) 1.4(L)	1.7(H) 1.5(M) 1.3(L)
1.5 Ball	1.3(H) 1.2(M) 1.0(L)	1.4(H) 1.3(M) 1.2(L)	1.2(H) 1.0(M) 0.9(L)	1.1(H) .95(M) .80(L)
1 Ball	.56(H) .48(M) .41(L)	.70(H) .60(M) .50(L)	-	-
0.8Ball	.37(H) .26(M) .16(L)	.42(H) .33(M) .24(L)	0.3(H) 0.3(M) 0.3(L)	0.3(H) 0.3(M) 0.3(L)
0.5Ball	.09(H) .07(M) .05(L)	.10(H) .08(M) .06(L)	.14(H) .10(M) .06(L)	.09(H) .07(M) .05(L)

COST CALCULATOR

The idea of developing a cost calculator is to have a proper cost and time comparison of copper and graphite milling and to facilitate costing of milling. By providing the required inputs it is intended to obtain the results expected as out puts.

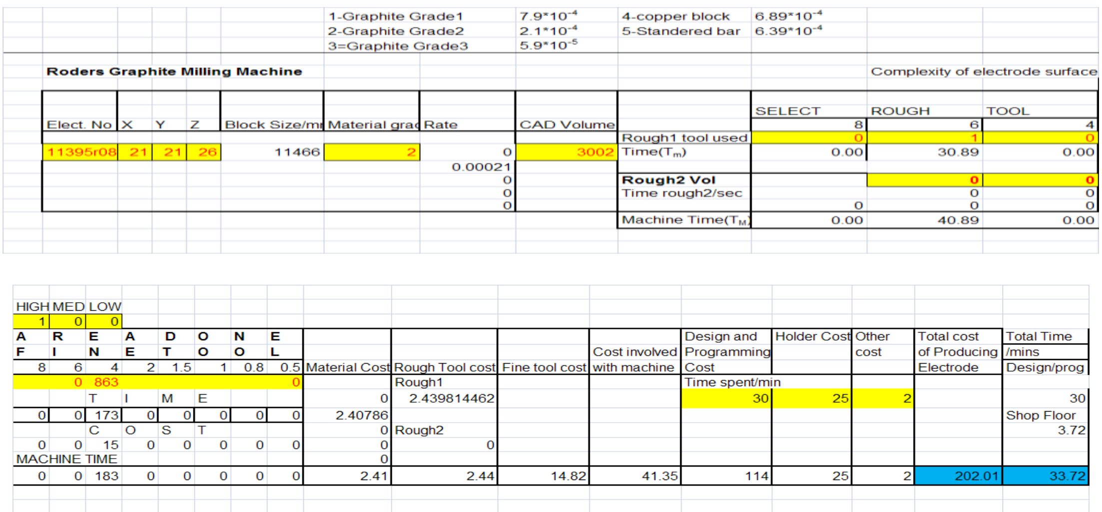

Figure 1: Shows the Cost Calculated Developed in Excel Sheet

Calculation of the cost of an electrode,

Cost of Electrode C_e $=$ $(C_g \text{ or } C_c) + C_h + C_M + C_d + C_o$

$C_M = C_m + C_t$

$C_t = T_M * R_t$

$C_m = R_m * T_m$

$T_m = T_M + t$

Here, C_g Cost of graphite; C_c Cost of copper

C_h Holder cost (reusable holders)/use; C_M Milling cost

C_d Design and Programming cost of electrodes

C_o Other costs such as examination hand work, etc involved with electrode production (no considerable difference observed in copper and graphite if proper machining methods are used to avoid burr)

C_t Tool cost; C_m Machine cost

R_m Machine Rate (including labour, coolant, Power and other overheads)

T_m Machine time (sec); T_M Milling Time (sec)

R_t Cost of a tool per second

t Other times(time associated with the machine: tool change, loading, unloading, etc) in secs.

All costs are converted to SEK

For rough milling $T_M = (X*Y*Z - v)/ MRR$

$t = 10$ seconds per tool

$T_m = T_M + t$

Average MRR is taken for copper rough milling.

For fine milling, Time for fine milling $T_M = A / R_f$

$t = 10$ seconds per tool

$T_m = T_M + t$

Here, X is x dimension of the block. Y is y dimension of the block.

Z is z dimension of the block. T_M is milling time of an electrode.

T_m is machine time of an electrode. A is Area finished by a tool.

R_f is fine milling rate of a tool taken from Table 07-Table 10, from three categories according to the complexity of the electrode. Category was decided by an experienced tool maker.

HI for high complexity. MEDIUM for medium complexity. LOW for low complexity.

Machine cost (C_m),

Machine rates are taken from the company book values.

Machine rate R_m, includes cost of robot arm for loading unloading, coolant costs, administrative, power, tool, maintenance, operator (direct and indirect cost related with the CNC machine).

SNC 64 machine rate	=	0.175	SEK/sec
Röders machine rate	=	0.185	SEK/sec
Hyper5 machine rate	=	0.105	SEK/sec
Machine cost (C_m)	=	$R_m * T_m$	SEK

Here R_m is machine rate. T_m is machine time.

Milling tool costs (C_t),

Diamond coated magaforceGraph'X 8529G K15 carbide) 8000HV

Tool life Grphite-Fine-7200secs Tool life Grphite-Rough-8200secs

Hard’X coating magaforceHard'X 8529H K15 carbide) 3000HV

Tool life copper-Rough-10000secs Tool life copper-Fine-9000secs

P_t = Dealer price at factory (Euro)*Exchange rate

R_t = P_t / T SEK/sec

C_t = $R_t * T_M$ SEK

Here, Dealer price at factory is all inclusive cost in SEK

P_t	Price of milling tool	SEK
R_t	Tool cost per milling second	SEK/sec
C_t	Tool cost	SEK
T	Tool life	sec
T_M	Milling time	sec

Milling cost (C_M)involves tool cost and machine cost,

C_M = $C_m + C_t$

Here C_m	is machine cost	SEK
C_t	is tool cost	SEK

Electrode design and programming cost,

This cost can be estimated by an experienced tool maker by looking/imagining the electrode,

$C_d = R_d * H$

Here, R_d is Rate (cost) for programming and design of electrodes

H is time (minutes) needed for an electrode to be designed and programmed.

Other costs incurred in milling electrodes include fixing, examination, naming, polishing, (if necessary), placing, handling, etc.Excel sheet was developed using the stated calculation procedure to calculate the cost and time of producing an electrode. It is possible to change the values if this to be customized to another machine or a company.

Outcomes and further improvements of the cost calculator,

- Cost of milling an electrode in any machine.
- Time required producing an electrode in any machine.
- Flexibility is provided to change the rates for customization.
- This cost calculator can be extended to calculate the mould cost

  Mould Cost = Mould Design Cost + Electrode cost + EDM Cost + other costs.
- It is noted that the MRR and the fine milling rate are the most important parameters in all these calculations. Since these will be changed with any modification or improvement with the machine or machine parameters. Therefore it is advised to continuously evaluate the accuracy of MRR and fine milling rate for all machines.

RESULTS & DISCUSSIONS

Table 5: Validation of Results Obtained Using cost Calculator for Röders Graphite Machine

Prog /Tool No	Complexity	Initial volume (mm^3)	CAD volume (mm^3)	Surface area (mm^2)	Milling time actual (sec)	Time(cost calculator) (sec)	Error (%)
14569r400		28800					
6mmBall	M		6157		79	77	2.5
4mmBall	M			2142	398	404	1.5
14569r401							
4mmBall	L	21600	8693		74	73	1.3
4mmBall	L			1852	329	331	0.6
11446b500							
8mmBall	H	308000	117530		341	350	2.6
8mmBall	H			11200	1577	1563	0.8

Table 6: Validation of Results Obtained using Cost Calculator for SNC 64 Graphite Machine

Prog /Tool No	Complexity	Initial volume (mm3)	CAD volume (mm3)	Surface area (mm2)	Milling time actual (sec)	Time(cost calculator) (sec)	Error (%)
14569r400		28800					
6mmBall	M		6157		79	77	2.5
4mmBall	M			2142	452	486	7
14569r401							
4mmBall	L	21600	8693		74	73	1.3
4mmBall	L			1852	384	402	4.6
11446b500							
8mmBall	H	308000	117530		341	350	2.6
8mmBall	H			11200	2313	2383	3

Table 7: Validation of Results Obtained using Cost Calculator for Hyper5 Copper Machine

Prog /Tool No	Complexity	Initial volume (mm3)	CAD volume (mm3)	Surface area (mm2)	Milling time actual (sec)	Time(cost calculator) (sec)	Error (%)
11395r08		4275					
6mmTip			1840		363	357	1.6
4mmBall	L			863	220	210	4.5
11395f03							
6mmTip		5400	3002		270	360	3.7
6mmBall	L			1068	267	260	2.6

Table 8: Validation of Results Obtained using Cost Calculator for Röders Copper Machine

Prog /Tool No	Complexity	Initial volume (mm3)	CAD volume (mm3)	Surface area (mm2)	Milling time actual (sec)	(Time)cost calculator (sec)	Error (%)
11395r08		4275					
6mmTip			1840		514	496	3.5
4mmBall	L			863	201	188	6.4
11395f03							
6mmTip		5400	3002		504	488	3.1
6mmBall	L			1068	288	305	5.9

Table 9: Comparison of Copper Milling

Electrode No	Milling Röders(cu)	Time(sec) Hyper5	Cost(SEK) Röders(Cu)	Hyper5
11395r08	678	562	313	249
11433f416	2977	2202	889	566

Table 10: Comparison of Graphite Milling

Electrode No	Milling Röders/Gr	Time(sec) SNC 64	Cost(SEK) Röders/Gr	SNC64
11395r08	170	213	197	207
11433f416	479	562	294	312

- Above results (Table 5, Table 6, Table 7 and Table 8) show that the error % of the time values calculated by cost calculator is less than 7 %. Therefore, it is recommended to integrate with the existing costing system.
- Copper is only recommended for small (<15*15*25) and essential (approximately VDI 12- mirror finish) areas to achieve a special surface(Use the fact that Graphite EDM is faster).

- Further it is necessary to carry out experimental analysis on the EDM machines available at tool maker to incorporate EDM data in the cost calculator for the final recommendations.
- It is possible to customize the cost calculator for different machines by changing the MRR and Fine milling rate.
- Improve on MRR and $R_f$continuously.

CONCLUSIONS

1. The comparison of milling of copper and graphite is achieved before milling the electrode, using the cost calculator is accepted and it can be used to calculate costs and time of milling.
2. MRR and fine milling rate calculated for the machines are direct indicators of the machine capabilities.
3. Graphite is faster EDM electrode materialthan copper for the available machinery.

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