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GRAPHITE VS. COPPER

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The Search Continues: Graphite or Copper, Which to Choose?

When determining the best EDM electrode material to use, the debate between graphite and copper has been long standing and is yet to be resolved. Many argue that graphite is the preferred electrode material while others stand firm with their preference for copper. Depending on the geographical region, the answer is most always the same. In North America, the preferred electrode material has shifted from copper in the beginning to graphite today. For Europe and Asia, some may argue that copper is the preferred material; however the use of graphite in these regions is steadily increasing. Without question, as depicted in *Chart 1*, graphite is the predominant material in the United States with at least 95% of electrodes being produced from this material. Steady increases of the use of graphite in Europe over the past decade have resulted in an electrode material ratio of 75% graphite / 25% copper. Asia follows closely behind with estimations of 45% graphite / 55% copper and the use of graphite continually rising. With over 70% of the global market using graphite electrode materials over copper today, perhaps the better question is not which is the best EDM electrode material to use, but instead what is causing this global change in the industry? In order to answer this, we must first identify the differences of each material to one another.

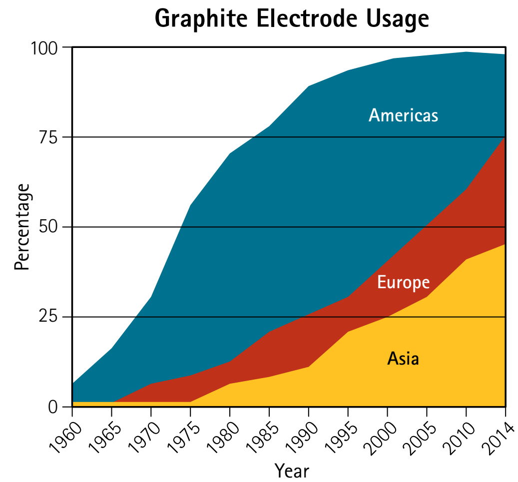

Chart 1: Chart showing projected graphite usage in world markets over past five decades.

Factors to consider for each electrode material include:

Material Variety

Graphite is produced with a wide range of material characteristics in order to allow matching the electrode material properties to the EDM application. Less critical applications with electrode features containing a large radius, an open tolerance or minimal EDM requirements would use an electrode with large particles, lower strengths and economical price. However, a highly detailed EDM electrode with critical features, extreme tolerance and stringent EDM requirements would entail a more premium graphite electrode to fit the needs of this application. On the other hand, the types of copper available on the market are few and therefore minimize the ability to match material characteristics to the EDM application, thus limiting optimum performance.

Electrode Cost

When considering material cost, the common concept is that copper is priced much lower than graphite. This may be true if only the material cost is taken into account and not the cost of machining the electrode. In addition, this statement is usually made after comparing the price of the copper material against the price of the more expensive graphite materials on the market. With the wide range of graphite materials available, it is quite possible that some EDM grades are more economical than copper. Even with the more expensive graphite materials, the machining costs often offset any savings that is realized with the copper. For example, a simple electrode blank with a ground finish on top and bottom was quoted with the material cost alone of copper being $4.68 per cubic inch while a premium grade of graphite was quoted at $6.80 per cubic inch or 45% more costly. However, when the cost of machining an electrode detail was included, the story changed. In this case, the graphite electrode was actually quoted at less than 20% of the cost of the copper electrode.

So, obviously there is something about the machining of copper that significantly increases the electrode cost. Due to the soft "ductile" characteristic of copper, this material is often gummy and conventional machining practices, such as feeds and speeds must be altered to successfully machine this material. The end result is lengthy machining times and increased costs. Tellurium Copper is easier to machine, but this may jeopardize EDM performance. Graphite on the other hand, is not gummy and can be conventionally machined very easily and quickly when compared to copper.

Electrode Detail

Copper does not have the ability to handle current density as effectively as graphite; therefore features on a single copper electrode should be similar in detail. Graphite actually performs very well at a high current density even with complex geometry. For this reason, graphite electrodes provide the ability to design various intricate machined details on the same electrode. For this reason, the number of electrodes required to perform a job can be significantly reduced. *Figure 1* shows the results of one shop that combined several electrode details into one graphite electrode instead of multiple copper electrodes. With copper, this particular job required over 100 electrodes to complete the job while graphite required less than 30. In addition, the copper electrodes required handwork to remove any burrs caused by the machining process whereas the graphite electrodes milled smooth and no burr removal was required.

EDM Performance

MRR – The thermophysical properties of the electrode material determine the ability to process the energy of the EDM cut and remove metal. In generating a spark, peak current is discharged only after the gap between the electrode and work piece is broken down. At this point, the electrode emits electrons that collide with the molecules of the dielectric fluid. As a result, the fluid is vaporized and an energy channel is formed allowing the spark to take place. With copper electrodes, the phenomenon of releasing electrons; thus forming carbon in the gap takes place only after its own material has melted. This is why on-times for copper electrodes are generally much higher than a

Figure 1: Photo showing number of electrodes required for one specific job.

graphite electrode. On the other hand, a graphite electrode is able to emit these electrons at much lower temperatures and the time required to form the energy channel is considerably less. Therefore, graphite initializes the spark faster, resulting in significantly higher metal removal rates.

EW – Electrode wear is a concern of every EDM operator as excessive wear results in adding electrodes or redressing electrodes more often. Graphite is able to achieve electrode wear of less than 1% in relation to the depth of cut at machine parameters much more aggressive than copper electrodes. This means that the high amperage and long on-times of a roughing condition actually preserve the graphite electrode while the copper electrode erodes away at these settings. On the contrary, in the finishing stages with low amperage and on-times the graphite electrode has a tendency to wear at a faster rate than copper. However, since the electrode wear is in relation to the amount of material removed in the cut, the wear percentage, in the finishing stage, is still minimal with a graphite electrode.

SF – It goes without saying that copper electrodes provide very fine surface finishes. With the sophistication of today's EDM sinker technology the surface finish gap between graphite and copper has narrowed significantly. Fine grain graphite electrodes are now able to deliver similar surface finishes much faster than copper with comparable wear on the electrode. With the proper electrode material selection and machine parameters, graphite is able to achieve near mirror finishes without powder additive and mirror like finishes with this additive. As shown in *Figure 2*, EDM test cuts measuring .260" x .510" were conducted on a test piece. The two pockets on the right were machined to a depth of .100" with an 8 VDI finish. While copper may still be able to achieve finer surface finishes, the requirement for an EDMed surface finish less than this is rare and even then are usually achieved with some type of post-EDM polish operation.

Figure 2: Photo showing fine surface finish available with an appropriate graphite electrode material and proper machine parameters.

Determining the True Cost

So where does this lead in our search for the "perfect electrode material?" While there is absolutely no perfect material for all EDM applications, if you consider the factors discussed here, we may have a better understanding on the reason why graphite is becoming the preferred material on a global scale. Unfortunately, this tells only a portion of the story as a Cost of Ownership calculation must be performed in order to determine the true cost effect that an electrode material has on the EDM operations. In order to identify the monetary impact of both graphite and copper electrodes, test burns were completed and performance tracked. With the results of this testing, the true cost was identified and the Cost of Ownership determined.

Test Case

The parameters of these tests were to EDM identical electrode details to a depth of 1" using two electrodes (1 rough and 1 finish) and then determine if additional electrodes were required to complete the job. For these tests, the electrode detail was not critical and a standard rib was chosen for simplicity. Each rib measured 0.040" thick by 1.00" wide with a 1° draft. For the sake of time, a final surface finish of 20 VDI was chosen. Two test plates were clamped together with the rib detail EDMed on the center line. This allowed for the plates to be separated and results measured on the corresponding halves.

The electrode materials chosen were a POCO EDM-3® graphite electrode in the "Ultrafine" classification and an "oxygen free" C110 copper electrode.

In order to eliminate any outlying data points, these tests were conducted on three different name brand EDM sinkers. The intent with this was to normalize EDM performances and provide a more rounded result by using the average from the results of all three tests.

Electrode Preparation

Electrodes were purchased on the market with material and machining at the normal rate. These parts were made to print with tolerances indicative to industry standards. The machining procedures were left to the discretion of the company machining the electrodes. Since the material grade was specifically identified, no substitutions were allowed for either the graphite or copper electrodes. Therefore; the electrodes with the lowest cost for each grade was chosen to allow for the most economical cost basis when determining the price/performance ratio for these tests.

EDM Programming

The EDM program for each test was generated using the standard technologies for each EDM sinker. For graphite, the "High Grade Graphite versus Steel" technology was used, while a "Copper versus Steel" technology was used for the metallic electrodes. In addition, the adaptive control feature was implemented for each test cut to simulate a "real world" EDM application. Since no flush hole could be machined into the electrode, external flush lines were used with a flush pressure of 3 – 5 psi. No operator intervention, such as "tweaking machine parameters" occurred during any of the testing.

Data Collection

In order to determine the impact of these electrode types on the EDM process, data was gathered from each series of tests. This included the cost of the electrode, the time of the EDM process, the amount of end wear for both the roughing and finishing electrodes, and the final surface finish achieved.

Electrode Cost – The electrode cost includes the value for both material and machining. This provides an overall electrode price without one component of electrode fabrication carrying a greater value factor than the other.

EDM Time – The time required for the test was taken directly from the time record on each EDM sinker. This measurement was collected for each step in the EDM program and added to determine the overall time from start to finish. While the time varied significantly from one machine to another, the Cost of Ownership Model takes into account the average of all three EDM tests.

Electrode Wear – All electrodes were measured before and after each test to determine the amount of wear during the burn. This measurement was taken on an independent height gauge and calculated to determine an End Wear percentage in relation to the depth of the roughing and finishing cut.

Surface Finish - The surface finish was measured after each burn while using a portable profilometer. Measurements for surface finish were taken at six locations in each cavity with three being at the top, middle and bottom of the cavity, and with the workpiece rotated 90 degrees, another three measurements from the left, center and right. These measurements were then averaged to arrive at a final surface finish for the complete burn.

Test Results

Electrode Cost

As stated earlier, a copper electrode could be more economical than a graphite electrode when only the blank material is taken into consideration. However, when the cost component of machining is factored in, the story changes considerably. For this test, the cost of each EDM-3 graphite electrode was $15.50 while the C110 copper electrodes cost $95.00 each. The intention was to use only two electrodes for each test with only one roughing and one finishing electrode. Two of the three EDM models used in this test generated programs for two electrodes. However; the graphite program for one EDM model called out for an additional finishing electrode. In this case, a third graphite electrode was used to eliminate operator intervention and bias. This test will be used to determine the cost basis for electrodes. Both the EDM-3 and C110 electrode materials are considered to be a high quality electrode material in their respective categories. Of course, these costs could be reduced with a more economical electrode material of lesser quality. For the purposes of determining value, the total cost for the EDM-3 graphite electrodes was $46.50 and $190.00 for the C110 oxygen-free copper electrodes.

EDM Time

Very interesting is the fact that all three EDM sinker brands used in this project programmed the copper electrodes at much higher on-times than the graphite electrodes. This adds credence to the statement made earlier that it takes longer for the copper electrodes to break down the gap; therefore reducing the metal removal rates. This was found to be true in all three accounts with the graphite electrodes completing the burn at a faster rate than the copper. Depending on the sinker used, the EDM-3 electrodes completed the burns 28% to 171% faster than the copper electrodes. Taking into account the average burn times for all three tests, the copper electrodes completed the burn in 4 hours and 29 minutes whereas EDM-3 had an average burn time of 1 hour and 54 minutes or 136% faster. For the purpose of projecting the value of the EDM process, the Cost of Ownership Model will use an hourly shop rate of $55.00.

Electrode Wear

To say which electrode material achieved the least amount of electrode wear would be difficult as both materials performed well in their respective category with the machine technology used. For the roughing electrodes, as can been seen in *Figure 3*, the graphite electrode on the top did have a larger corner radius than the copper electrode on the bottom, yet had a much smoother edge. The rough edge on the copper roughing electrode will cause the finishing electrode to work much harder to achieve a clean burn depth in the cavity. In the roughing operation, the copper electrode did have slightly less end wear. However, both materials achieved wear percentages comparable to the electrode detail and machine parameters. *Figure 4* shows the opposite with the graphite electrode having reduced corner wear and achieving a cleaner cavity. The corner wear on the copper electrode could have been enhanced with an addition of a third electrode; however this would have further increased material costs and burn time. Not taking corner wear into account, the graphite electrode had an overall (roughing and finishing) wear percentage of 2.75% while the copper electrode achieved an end wear ratio of 0.42%.

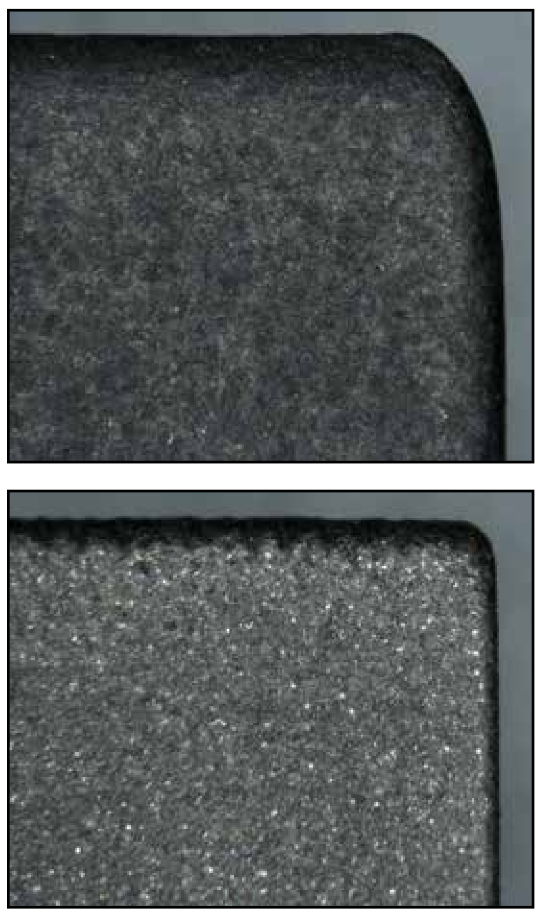

Figure 3: Roughing electrodes: Graphite on top, Copper on bottom

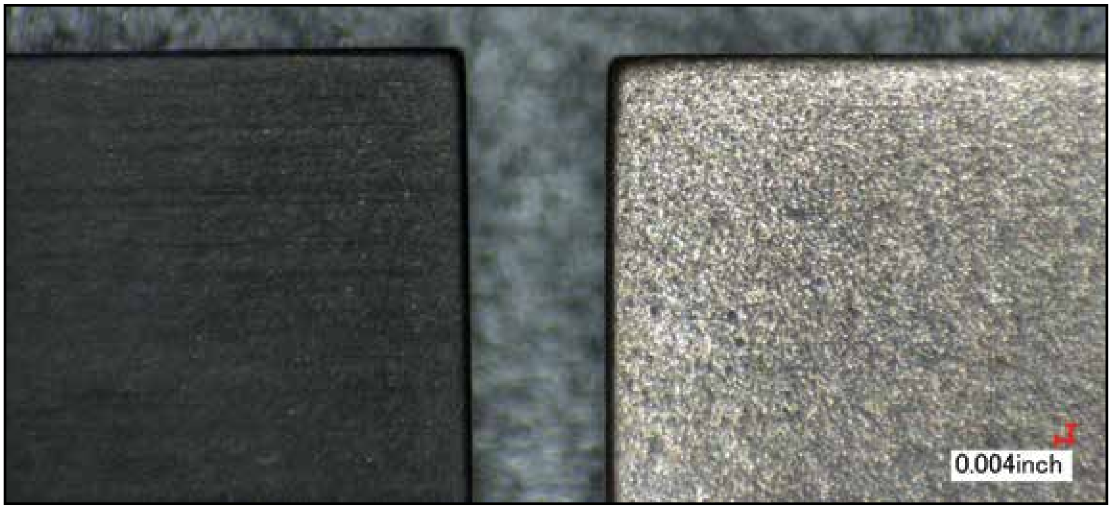

Figure 4: Finishing electrodes – Graphite on left, Copper on right

Surface Finish

Depicted in *Figure 5* is a 25x magnification of the surface finish in the each cavity. As expected, because it is cast as a solid material with no porosity, the copper electrodes achieved a slightly finer surface finish in the cavity than the graphite. However; neither electrode material met the surface finish prerequisite of 20 VDI. Using an average of six measurement points, the graphite achieved at 24 VDI finish while the copper had a surface finish of 22 VDI. With both electrode materials, a post-polishing process will be required to bring the final surface finish to the required 20 VDI finish. With an estimation of $15 per square inch of surface area per VDI point, the cavity produced with the graphite electrodes would have $60 in polishing costs while the cavity produced with the copper electrodes would have $30 in polishing costs.

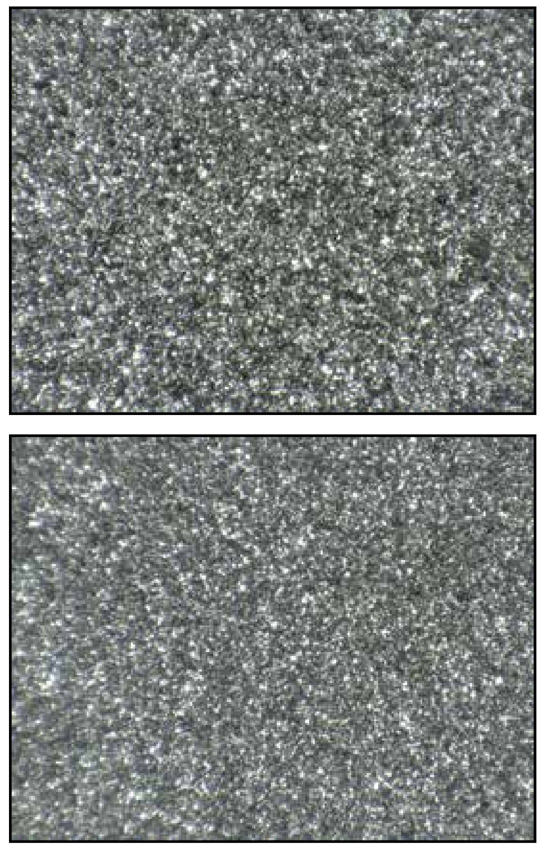

Figure 5: Surface finish in the cavity – Graphite on top , Copper on bottom

Cost Model

The Cost of Ownership Model is useful in determining the monetary effect on a production process. Most often, only the cost of the electrode materials are taken into account in EDM operations, however the model also takes into account the cost of EDM, any required post-polishing and the added available throughput on a shop rate basis.

As can be seen in *Chart 2*, the costs associated for each electrode type are broken down to the primary factors of EDM. This model breaks these costs down by category and then calculates a bottom line “Total Effective Cost” for the entire EDM operation. Even with adding an additional graphite electrode and a slightly higher post-polishing cost, the total cost of production without taking increased throughput into account shows a clear and distinct difference. The costs associated with the EDM-3 graphite electrodes totaled $211.00 while the costs associated with the C110 copper electrodes totaled $466.95, or an increase of 121%. Taking throughput into account, creates a credit that is applied toward the costs of the electrode material allowing for increased productivity, or in this case for EDM-3. With this value, the Total Effective Cost for EDM-3 is reduced to $68.90 while the cost for the C110 copper electrodes remains the same at $466.95. In the end, the production costs for the C110 copper electrodes is 578% higher than EDM-3.

Conclusion

Of course, many assumptions can be made regarding the test methods for this project. This could be not using the same machine technology, the same number of electrodes or the electrode detail not being fully suited to one type of material. With the myriad of variables that could be associated with these tests, the intent was to reduce these as much as possible and provide the end results. It would then be up to you, the reader; to conduct testing of your own to determine which material would provide the most cost effective operations.

However, one thing is certain. In this industry, we don’t sell molds. We sell time and time is money. All too often, only one factor in the cost model is taken into account and decisions are based on this. In order to fully determine which electrode material is best, graphite or copper, all factors must be considered together to determine the total effective cost. The choice is yours.

Cost Comparison of Graphite to Copper				
		Graphite	Copper	Variance
Electrode Cost	3@ $15.50	$46.50		
(Material & Machining)	2@ $95.00		$190.00	+ 308%
EDM Burn Time	(Avg / 3 burns)	1 hr 54 min	4 hr 29 min	
EDM Cost	($55 / hour)	$104.50	$246.95	+ 136%
Final Surface Finish (VDI)	(Avg / 6 locations)	24	22	
Polishing Cost	($15 / in^2 / VDI)	$60.00	$30.00	- 50%
Total Cost of Production		$211.00	$466.95	+ 121%
Added Throughput		2 hr 35 min	N/A	
(Time Saved on EDM)	($55 / hour credit to cost)	($142.10)	$-	N/A
Total Effective Cost		**$68.90**	**$466.95**	**+ 578%**

Chart 2: Cost of ownership model illustrating the total effective costs of each material

EDM Technical Manual

The POCO EDM Technical Manual is now available online at www.EDMTechMan.com or as an app for your iOS or Android device.

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