

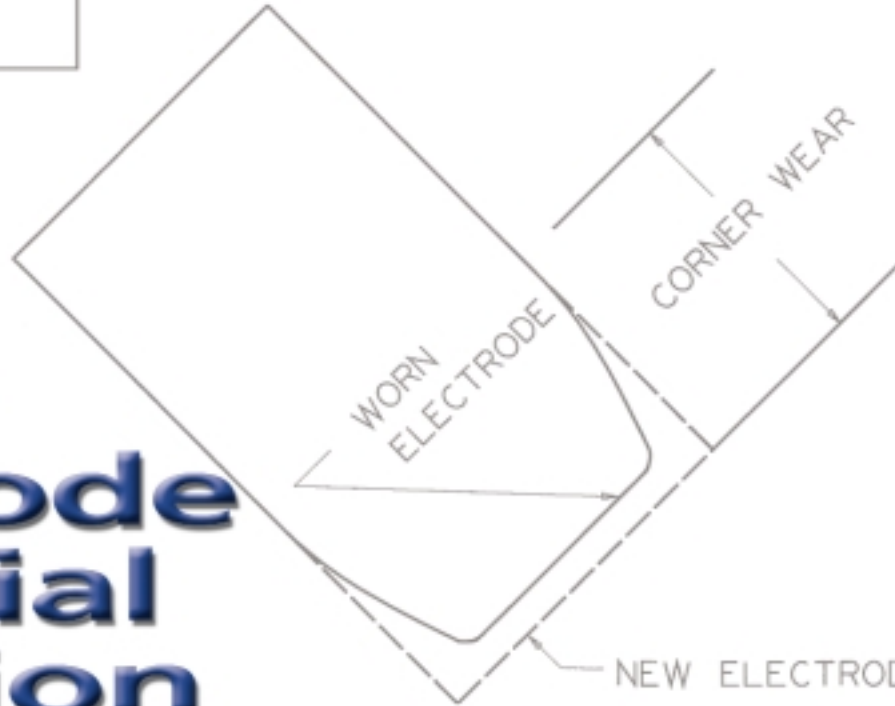
TechTips



by Roger Kern

sinker electrode material selection

The selection of the most appropriate Sinker EDM electrode material is a key decision in the process plan for any Sinker EDM job. This article will examine the properties of metallic and graphite electrode materials, as well as make applications recommendations.



Electrode Material Properties That Effect EDM:

Electrical Conductivity

Since electric current is our “cutting tool”, higher conductivity (or conversely, lower resistivity) promotes more efficient cutting.

Melting Point

Since EDM is a thermal process, it would be logical to assume that the higher the melting point of the electrode material, the better the wear ratio will be between electrode and workpiece.

Chemistry

Just as in the case of Wire EDM, the chemistry of the electrode material

can significantly affect the efficiency (as measured by speed and wear) of the EDM process.

Structural Integrity

Even though EDM is often thought of as a “zero force” process, each individual spark is a very violent process on a microscopic scale, exerting considerable stress on the electrode material. How well the material responds to hundreds of thousands of these “attacks” on its surface, will be a significant factor in determining the electrode material’s performance regarding wear, surface finish, and ability to withstand poor flushing conditions.

Mechanical Properties

The mechanical properties most often measured for electrode materials are:

- Tensile strength
- Transverse Rupture Strength (if applicable)
- Grain Size (if applicable)
- Hardness

These mechanical properties will affect both the fabrication of the electrode, and its performance in the EDM process.

Manufacturability

The usefulness of an electrode material is partially determined by the difficulty of manufacturing useful electrodes from it. Such factors may include:

- Machinability
- Stability
- Burr formation and removal

Cost

Definition and Measurement of Electrode Wear

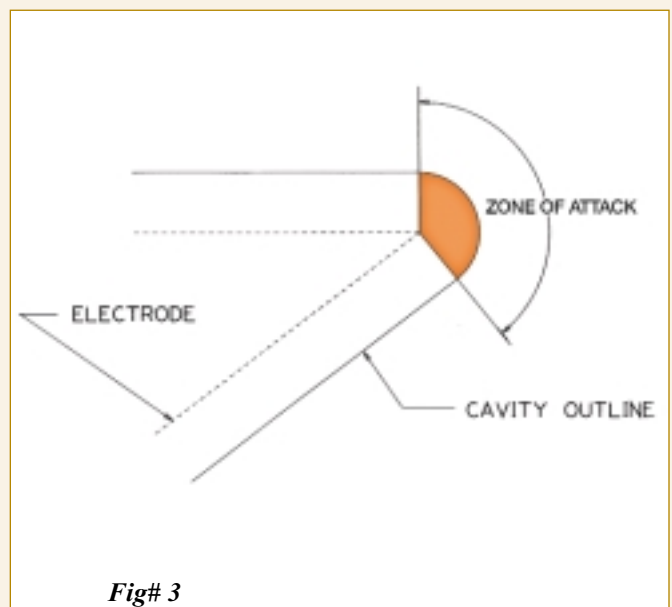
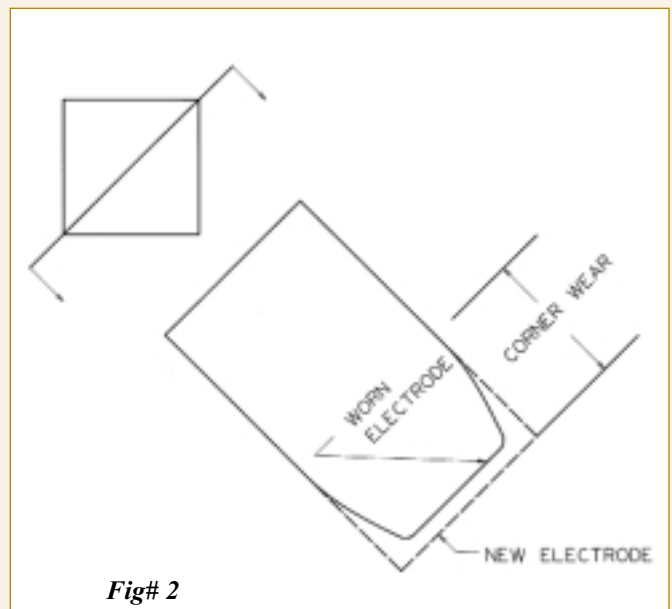
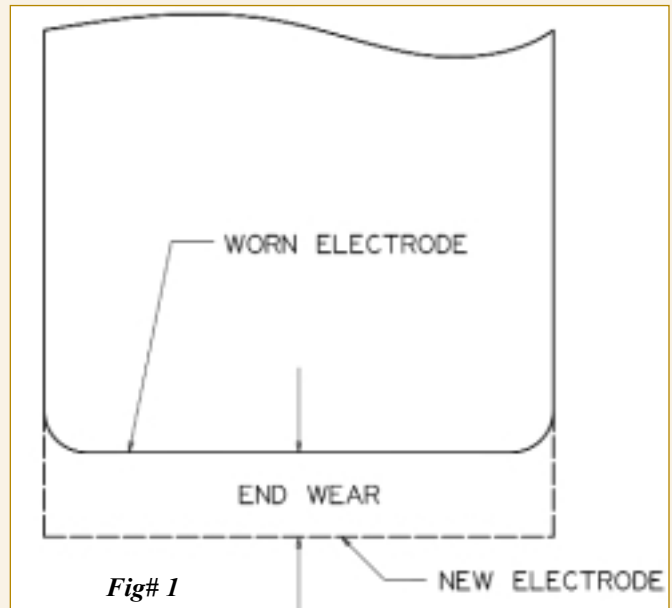
Prior to delving into the analysis and comparison of electrode materials, let's take a moment to discuss and define this key factor in the Sinker EDM Process. Two measurements are necessary to fully define electrode wear:

End Wear

End wear is the percentage ratio of the amount of electrode material lost from the bottom end of the electrode, to the depth of the cavity burned. (See Fig# 1)

Corner wear

Corner wear is the percentage ratio of the length lost (measured in the burn direction, usually Z) of a 90 degree external corner on the electrode, to the length of the corresponding sharp internal corner produced in the cavity. (See Fig#2) It should be noted that corner wear is almost always significantly greater than end wear, because the corner is being attacked by a multitude of sparks from many directions simultaneously. It should also be noted that corner wear is dramatically affected by the included angle of the electrode external sharp corner, since corner wear is a function of the surface-to-volume ratio of the corner condition. (See Fig# 3)



Low Wear Burns

Electrode wear is not just a function of electrode properties, but is also a function of power supply settings. The physics of the low wear process is beyond the scope of this article. However, a simplified version is that with certain electrode-workpiece pairs, polarity, peak current and on-time combinations, material lost from the electrode surface is “re-plated” back onto the electrode surface during the spark duration. It should be noted that the re-deposited material is a combination of electrode, workpiece, and dielectric, and thus may have different properties than the electrode material itself. Low wear burning is usually associated with electrode positive polarity and long on-time. Under extreme conditions, it is possible to have the electrode actually grow rather than wear. Needless-to-say, this is not a desirable condition, since control of the electrode (and thus the cavity) dimensions is lost under these conditions.

Metallic Electrodes

In the early days of EDM (tube type power supplies and R/C generator circuits) metallic electrodes were used exclusively. Today, metallic electrodes are only used in perhaps 10% of Sinker EDM applications (with the exception of small hole drilling). The primary advantage of metallic electrode materials is their electrical conductivity and mechanical integrity. Mechanical integrity is especially important in both sharp corner and poor flushing conditions (those subject to DC arcing). The primary disadvantages of metallic electrodes are difficulty in fabrication and low cutting speeds. Let’s examine the most common metallic electrode materials in further detail.

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.

Copper

With development of the transistorized, pulse-type power supplies, Electrolytic (or pure) Copper became the metallic electrode material of choice. This is because the combination of Copper and certain power supply settings enables low wear burning. Also, Copper is compatible with the polishing circuits of certain advanced power supplies. Many shops in both Europe and Japan still prefer to use Copper as the primary electrode material, due to their tool-making culture that is averse to the “untidiness” of working with graphite. Due to its structural integrity, Copper can

produce very fine surface finishes, even without special polishing circuits. This same structural integrity also makes Copper electrodes highly resistant to DC arcing in poor flushing situations. Copper is frequently used to make female electrodes on a Wire EDM for subsequent use in reverse burning punches and cores in the Sinker EDM.

There are a number of significant disadvantages associated with Copper electrodes.

- Copper electrodes will generally burn only half as fast as graphite electrodes.
- Copper is a soft and gummy material to machine or grind.
- Copper is an extraordinarily difficult material to de-burr. It can take longer to de-burr a Copper electrode than to manufacture it.

The addition of 1-3% Tellurium to Copper improves its machinability to a level similar to brass, eliminating the “gummy” properties normally exhibited by Copper when it is machined or ground.

Unfortunately, the EDM performance of Copper is somewhat compromised by the addition of the Tellurium. Compared to Electrolytic Copper, Tellurium Copper (also known as TELCO) exhibits 15-25% higher wear and 10% decreased metal removal rate.

However, because of the ease of machining this material, most shops are willing to accept this trade-off.

Most Copper comes in the “as rolled” condition. Being a cold rolled material, the bars exhibit a significant amount of stress movement, especially when being machined by Wire EDM cutting.

Copper is also commonly used for tubing for certain brands of High Speed Small Hole Machines. Copper electrodes are also the preferred material for all High Speed Small Hole applications involving aerospace alloys as well as Carbide.

Silver

Silver is occasionally used as an electrode material, due to its superior electrical conductivity, purity, and structural integrity. The use of Silver electrodes and fine finish power supplies can produce extraordinary fine finishes in coining dies, where the use of orbiting to improve the finish would distort the cavity detail. Obviously, due to the cost, Silver is rarely used.

Tungsten

Due to the combination of its high density, tensile strength, and melting point, Tungsten had been the electrode material of choice for certain limited EDM applications. It is important to note that Tungsten, due to its relatively poor electrical conductivity, cuts much slower than Brass or Copper. Also, due to its high cost and very low machinability, Tungsten is seldom used.

Copper Tungsten

Copper Tungsten (CuW) is a powder metal product designed to combine the best EDM properties of Copper and Tungsten. Copper Tungsten combines the high electrical conductivity of copper with the high melting point of tungsten. The combination of these two metals creates an electrode material with very good wear properties.

Copper Tungsten is unmatched for its wear resistance, holds up very well in sharp corners, and is readily machined and ground without the burr issues associated with Copper. Copper Tungsten is also the preferred material for EDMing Carbide.

Copper Tungsten cannot be manufactured by conventional alloying techniques, since the Copper would vaporize before the Tungsten began to melt. That is why Copper Tungsten is made by the powder metal process. Copper and Tungsten powder are pressed into a pre-form and then sintered. During sintering, the material shrinks by approximately 25% and great care must be taken to avoid porosity, which is a common defect in some Copper Tungsten electrodes (a porous spot will leave a bump in the EDM cavity). The better grades of Copper Tungsten are made by the Press-Sinter-Infiltrate process, which virtually eliminates porosity.

Copper Tungsten is generally sold in the 70W:30Cu grade. It is possible to purchase Copper Tungsten with different ratios. A higher Tungsten content would improve the corner wear at the expense of lower cutting stability and higher cost. A lower Tungsten content would suffer increased corner wear, but enable smoother burning in addition to reducing the cost of the material. (Copper is cheaper than Tungsten)

It is important to note that Copper Tungsten typically cuts only half as fast as Copper.

Silver Tungsten

Silver Tungsten is a powder metal product which combines the wear resistance of Tungsten with the high conductivity of Silver, to give an unmatched combination of low wear and fine surface finish for EDM applications with fine detail. Silver Tungsten is made by the same process as Copper Tungsten. Due to its high cost and limited availability, Silver Tungsten has a very limited range of applications.

Tungsten Carbide

Due to its extraordinary stiffness and low wear properties, Tungsten Carbide is often the preferred electrode material for applications requiring very small holes put in by sinker EDM or Small Hole EDM.

Since Tungsten Carbide is very brittle, it is best utilized with rotating spindles that have tilt and centering adjustments or guide bushings, since Carbide cannot be trued in the spindle by bending.

Graphite Electrodes

Graphite is the preferred electrode material for 90% of all sinker EDM applications. Thus, it is important that we expend considerable effort to understand its properties and application to EDM.

Graphite was introduced to the EDM industry approximately 50 years ago. One of the early well known brands of graphite was manufactured by General Electric, and known by the trade name of "Gentrod".

Graphite is made from Carbon derived from petroleum. The powdered Carbon is mixed with a petroleum based binder material and then compacted. How the graphite is compacted in this stage of production is vitally important to its ultimate properties. All early graphites were made by compressing the powder/binder mixture in only one direction, resulting in properties or "grain" similar to wood, that varied relative to the direction of pressing. As an outgrowth of the space program, methods were developed to isostatically press graphite such that its properties became "isotropic", that is the same in all directions. All high quality, high performance graphites are now manufactured this way. After compacting, the "green" compacted material undergoes a series of thermal treatments that convert the Carbon to graphite.

Graphite has certain properties quite different than wrought metal based electrode materials:

- Graphite has an extremely high melting point. Actually, graphite does not melt at all, but sublimates directly from a solid to a gas (just as the Carbon Dioxide in dry ice) at a temperature thousands of degrees higher than the melting point of Copper. This resistance to temperature, makes graphite an ideal electrode material.
- Graphite has significantly lower mechanical strength properties than metallic electrode materials. It is neither as hard, as strong, nor as stiff as metallic electrode materials. However, since the EDM process is one of relatively low macro mechanical forces, these property differences are not often significant.

Due to the significant differences between metallic electrodes and graphite, there are certain properties, unique to graphite, that are commonly specified and controlled:

- **Particle Size:** Generally, the smaller the particle size, the better the mechanical properties of the graphite, which result in finer detail, better wear, and better workpiece surface finish.
- **Density:** Since graphite is a porous material, density must be closely controlled. Generally, higher density is preferable.
- **Flexural Strength:** Flexural strength is a measure of the strength of the graphite. Generally, graphite with the smallest particle size has the highest flexural strength.

- **Hardness:** Hardness is often a function of the particle size, porosity, and binder material. Hardness can be very important to the success of machining and grinding operations.

Graphite is widely used due to its significant production advantages over metallic electrode materials:

- **Speed:** Graphite is faster than Copper in both roughing and finishing, usually by a factor of 2:1.
- **Wear:** Graphite usually wears less than Copper.
- **Surface Finish:** With advances in dielectric, power supply electronics, and orbiting, achievable graphite finishes match those formerly only attainable with Copper
- **Machinability:** Graphite machines and grinds an order of magnitude faster than Copper, and can also have more detail easily machined into it. Graphite doesn't have to be de-burred like any metallic does, further reducing electrode fabrication costs.

However, graphite also has some limitations, when compared to Metallic electrode materials:

- **Housekeeping:** Machining operations on graphite will produce prodigious amounts of graphite dust which, unless efficiently controlled, gets on everything and everyone in the shop. Just handling a piece of graphite will result in dirty hands. Graphite dust, while not particularly harmful to humans, can be fatal for CNC controls, lead screws, and ways. Housekeeping is the primary reason that European and Asian toolmakers resisted the adoption of this important technology. However, it is important to note that technologies for controlling graphite dust are readily available. Thus, the housekeeping issues today are far from insurmountable, and resistance to using graphite is more of a psychological issue for those toolmakers who insist on working in a "clean room" environment. In addition, burning with graphite also results in the production of significantly more debris that has to be filtered out of the dielectric oil.
- **Forgiveness:** When the flushing deteriorates due to unforeseen circumstances, graphite has a lower margin of "safety" with regards to DC arcing, when compared to metal electrodes. *(Please note that the word "safety" is related to the unintentional introduction of surface anomalies in the EDM surface, and not in any way related to operator or plant safety)* It is important to note that with the introduction of state-of-the-art power supplies, this factor is less important than with older machines, but significant nonetheless.

Graphite Grades

While there are a myriad of graphite grades available from numerous manufacturers, let's examine the most significant categories based upon particle size. When a graphite electrode is attacked by an EDM spark, a particle will often

be dislodged. Thus, particle size is the best predictor of the level of detail attainable, strength, corner wear, and surface finish.

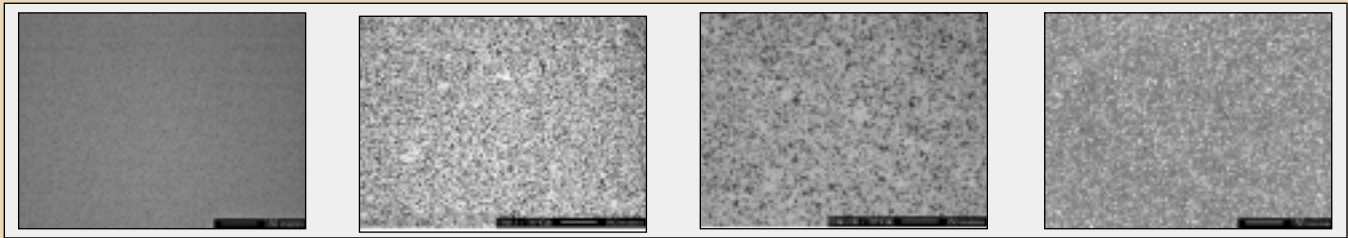
- **Sub Micron (See Fig# 4)** graphite features a particle size of less than one micron. This is the most expensive of the graphite grades, and will hold sharp corners and reproduce extremely fine detail.
- **Premium (See Fig# 5)** graphite features a particle size ≤ 5 microns. This grade is used for the bulk of demanding, small to medium, high precision mold work, die work, and aerospace production.
- **High Performance (See Fig# 6)** graphite features a particle size in the range of 10 to 20 microns. This grade is used for larger mold and die cavities, due to its more moderate cost
- **General Purpose** graphite features particle sizes in excess of 20 microns. These grades are often used for forging dies. However, with the advent of high speed hard machining, the demand for these grades has fallen considerably.

Please note that while there are many intermediate grades available, it is my opinion that most shops will not benefit from having a large number of grades out on the shop floor. In fact, the fewer grades the better, since it is virtually impossible to identify a specific grade of graphite if it is not marked. Making expensive electrodes out of the wrong grade can be an experience as painful as making a mold out of the wrong steel. Graphite raw material and cutoff pieces should always be identified with a recognized paint color code on one end. A brush-on water based paint from an art supply store is ideal for this purpose.

Copper Graphite (See Fig# 7)

Copper graphite is graphite manufactured with a controlled amount of interconnected porosity which is then infiltrated with Copper by capillary action in a furnace. The resulting material has increased electrical conductivity and mechanical strength. Copper graphite offers the combined benefits of the ease of fabrication of graphite, and the burn stability and "safety" of Copper. Copper graphite has shown particular advantage when applied to aerospace applications such as Titanium, Inconel, and other high temperature aerospace alloys. Copper graphite is also applied to the EDMing of carbide.

Copper graphite electrodes are not nearly as fragile as graphite electrodes. In fact, Copper graphite sheets are available in thickness down to .003". It should be noted, however, that Copper graphite suffers from increased corner wear when compared to the same non-impregnated grade. This is particularly noteworthy for tapping electrodes, which will exhibit significantly increased thread crest wear.



Fig# 4

Fig# 5

Fig# 6

Fig# 7

Courtesy of Poco Graphite

Additional Notes

Polarity

It is very important to pay attention to the recommended polarity of various electrode-workpiece combinations. The wrong polarity can have significant implications on speed, wear, and stability. It is best to consult the specific power supply technology documentation for polarity recommendations. General polarity guidelines are listed below:

Graphite on Steel: general purpose and low wear	Electrode Positive
Graphite on Steel: high speed and 20% wear	Electrode Negative
Graphite on Copper	Electrode Negative
Copper on Steel	Electrode Positive
Copper Tungsten on Steel	Electrode Positive
Copper Tungsten on Carbide	Electrode Negative

Cutting Speed

For a given surface finish, the electrode-workpiece and polarity combination can produce a dramatic range of cutting speeds as noted below (We will assume Copper on Steel is 100%):

Copper Tungsten on Carbide	25%
Copper Tungsten on Steel	50%
Copper on Steel	100%
Graphite Positive on Steel	200%
Graphite Negative on Steel	400%

Next issue: Sinker Dielectric Fundamentals.

Any suggestions for future topics are welcome. Tell us what you would like to read about.

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