THE ARCING PHENOMENON IN ELECTRICAL DISCHARGE MACHINING AND ITS EFFECTS ON THE MACHINING PROCESS

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Introduction:

In the Electrical Discharge Machining (EDM) process, transient electrical discharges are produced across a small gap spacing between an electrode (tool) and a workpiece and each discharge removes a small amount of metal from the workpiece. The surface finish, workpiece resolution and other characteristics of the finished workpiece are determined, in large part by the time-current characteristics of the individual current pulses. The machining rate is determined by the combination of the current waveshape of the individual discharges and the time between discharges or 'off' time.

In order to minimize machining time on a given EDM job, the 'off' time or time between discharges must be preset as short as possible. On the other hand, the 'off' time must be long enough that the machining gap space has recovered sufficiently to ensure random discharge locations. The recovery interval then is the time period following the electrical machining discharge during which deionization of the discharge column, thermal recovery, and electrode cooling take place. If the gap does not recover sufficiently between any two discharges, there is a high probability that succeeding discharges will occur at the same physical location on the workpiece surface. This result is well known in the art as "arcing" because it has essentially the same destructive effect on the workpiece as a long duration arc even though the current waveform comprises discrete pulses. If succeeding discharges occur at the same location, the workpiece and tool electrode become severely overheated in a localized region and a relatively large mass of the workpiece becomes molten, thus destroying the surface finish as well as the surface integrity. Consequently, for any EDM operation, there exists a critical minimum 'off' or recovery time for a given set of materials and electrical conditions.

This paper describes the "arcing" phenomenon in the EDM process, some possible reasons for its initiation and subsequent development, its influence on the EDM recovery time, and possible measures to prevent its initiation and associated damage.

In this experimental investigation, the recovery time was measured by using a "two pulse" technique which employs a primary rectangular shaped current pulse to simulate the machining discharge followed by a low-voltage, low-current monitoring pulse. The monitoring pulse is applied to the gap at a preset time delay after the termination of the primary current pulse. The delay time was varied from less than one microsecond to about 5 milliseconds for each primary pulse duration tested. Recovery is considered complete when the gap resistance reaches approximately 100 megohms.

The Damage Accompanying the Arcing Phenomena.

The destructive effects associated with the arcing phenomena occur because

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successive machining discharges occur at the same physical location on the workpiece surface. Damage can be very expensive even if as few as two or three discharges occur in that same spot. A succession of machining pulses in the same location can destroy the surface finish of the workpiece by overheating and thereby necessitate an expensive'hand re-finishing process. Typical workpiece damage from arcing is shown in Figure 1.

The effects of arcing can, therefore, take two forms: one producing extensive damage to both the tool and workpiece which is usually non-repairable and the other producing slight, but at times expensive damage to the workpiece surface. The first type of damage is more concentrated and thus more destructive. In this case the discharges are concentrated at the same physical location on the workpiece surface and carbon growths begin to form on the surface of the electrode and the workpiece (See Fig. 2). This growth process is loosely referred to as "coking" by machine operators owing to the similarity of the carbon growth to coke. These growths can occur in many different sizes, as shown in Figure 3. Extensive workpiece damage can be prevented if "coking" is detected- as soon as it starts, however once the carbon growths have appeared they cannot be easily eliminated by standard EDM machining action. The most efficient manner to eliminate the growths once they are established is to interrupt the machining and physically remove them from the electrode surfaces. It has been found by experiment that even a small piece of the carbon growth will act as a "seed" which causes other "coking" formations to develop. [1] Thus, the growths must not be left in the machining area or even in the machine filter system.

The second type usually takes the form shown in several of the machined cavities in Figure 4. Because of the rough burred appearance of the leading edge of the machined cavities, most EDM operators term this form of arcing as "burring". In a severe case of "burring" a workpiece can be extensively damaged and possibly destroyed. More often the damage is less severe and expensive hand finishing is required to salvage the workpiece. Additional information regarding "burring" will be presented later in this paper.

The Effects and Causes of the Coking Condition.

Until recently there has been very little, if any, published information regarding the coking condition. In the past, EDM operators had to rely totaily upon experience to tell them which combination of parameter settings should be used on a particular EDM machine to avoid coking and, oftentimes, the operator must constantly observe the operation to insure that coking does not occur. Generally, once coking develops on a machine, the procedure followed by many operators is to reduce the duty cycle and current output of the machine thereby reducing the overall efficiency of the EDM operation.

The practical knowhow accumulated by EDM operators has provided some clues as to when coking occurs. There is a greater tendency for coking to take place when carbon or graphite materials are used as the cathode electrode. Higher duty cycles also seem to cause the condition to occur more frequently Very seldom is "coking" observed for pulse durations below 20 micro-seconds, even with high duty cycles. Also, certain electrode material combinations have been found to be more prone to this condition than others.

There are several other properties of the coking condition that distinguish it from normal machine operation besides the obvious ones mentioned previously. When coking is occurring in the gap spacing, there is a marked decrease in the gap voltage of each machining pulse, an increase in the discharge current, and a remarkably stable machine operation. The os- oscillogram in Figure 5 shows a gap voltage and current waveform that exhibits the abrupt change that occurs when the arcing condition starts during the machining pulse. Referring to Fig. 5, the gap current and voltage waveforms are smooth and fairly noise-free after coking has begun compared to the earlier portion of the waveshape where there is no coking. When coking develops, consecutive current discharges occur in the same general location, causing an accumulative heating effect, which, apparently lowers the gap machining voltage. This effect causes higher currents and the formation of excessive amounts of machining debris in one particular location.

The reason the discharges tend to accumulate on one small area is the key to determining why coking occurs. It has been found that the coking, condition usually originates at the edge of the electrode machining surface. However, with larger machining surface areas, the condition can originate anywhere on the workpiece surface area. Grachis [2] has shown that the least amount of dielectric fluid flushing occurs at the edges of the machining surface for the case of center pressure flushing. Furthermore, the greatest amount of fluid contamination exists at the edges. The fact that the carbon growths usually occur at the edge of the machining surface suggests a possible relationship between the contamination level and coking.

Another key point in the coking process is: how does the carbon growth take place. Several investigators have conducted research on similar phenomena, but none describe processes which occur under conditions similar to those encountered in the EDM machining process. The descriptions given of a pyrolytic carbon process which is a method used to deposit carbon films on suitable substrates in a heated enclosure filled with a hydrocarbon vapor [3] makes no mention of voltage polarities or an arc being involved in the process. The graphite whiskers process, where an irregular carbon growth is produced using an electrical arc, [4,5] makes no mention of the effect of hydrocarbon gases found in EDM by products [6,7] upon the carbon growth mechanisms. Since both processes involve conditions similar to those known to be present in the gap spacing, it seems logical to conclude that some combination of the two growth mechanisms could account for the EDM coking growths.

The Effect of Coking on Recovery Times

Coking causes an accumulative heating effect, which in itself would cause the recovery interval to increase as a result of longer thermal recovery times. The resultant coking growths become unwanted machining electrodes. Moreover, the thermal effects are enhanced due to the smaller diameter of the growths. The growths are carbon in composition and therefore inherently produce higher temperature ionized gas column than most other electrode materials. [8]

The recovery times found during optimum EDM machine operation can be considered as the minimum recovery interval necessary for correct machine operation. The conditions and effects associated with the coking condition can only act to increase the recovery time interval. However, this maximum recovery time is not as important to the correct EDM machine operation as is the minimum recovery period. The results presented here are for the minimum recovery interval and if the results are used to keep the coking condition from occurring the longer recovery times will never influence the machining operating.

The coking condition was investigated by using several different workpiece materials and various tool graphites immersed in different EDM fluids, with both a tool cathode and tool anode configuration. The recovery time results are very similar in all cases tested. This similarity can be attributed to the fact that when coking occurs the machining discharge column terminates on the carbon growth instead of on the original electrode surfaces. Since the composition of the electrode termini of the discharge are similar, if not the same, the results would be expected to be similar. The tool anode and tool cathode polarity results using Product A on Hardtem B with a kerosene based dielectric fluid, Product B on 8416 Steel with a kerosene based dielectric fluid and Product A on #416 Steel with pure silicone dielectric fluid, are shown in Figures 6 and 7. A comparison of these results shows that they were very similar and all exhibited a constantly increasing recovery time with increasing pulse duration. It may be noted that the recovery times are much longer than those found under normal non-coking conditions. This increase is demonstrated by Figure 8 which shows a comparison of normal and coking recovery times.

The coking phenomena is undoubtedly the worst condition that can occur at the machining gap owing to its extremely long recovery times and the damaging results. However, the recovery times required for an actual machining operation may be as much as 5 or 6 times longer than the recovery times found with the experimental apparatus because of the closer succession of discharges in a machining condition. The rapid succession of discharges would produce a more cumulative heating effect than was observed in the experimental tests. The results also indicate that the type of materials used initially does not effect the coking condition except that certain materials produce the condition more easily than others. There is very little difference in recovery times for different electrode materials, different fluids, or different gap polarities.

Correlation of Recovery Times to the "Burring" Phenomena

In order to ascertain if a relationship exists between "burring" and the recovery interval, a comparison was made with tests on a commercial EDM machine. On the basis of operator experience it was determined that "buring" most frequently occurs when a graphite or carbon material is used as the cathode electrode. This observation is not surprising in light of the recovery time data. Graphite or carbon materials, as the cathode electrode, have longer recovery time than their metallic counterparts.

The EDM machine tests were conducted with a peak pulse current of between 60 and 70 amps. The pulse duration used was 8 microseconds in an attempt to avoid the "coking". The duty cycle of the pulsed output was varied from 20% to 80%, meaning that the time between consecutive pulses was varied from 32 to 2 microseconds.

During the tests it was found that "burring" did not occur at the lower duty cycle settings but it did appear for all duty cycles greater than 35% [9]. If the "burring" is a result of the application of a second discharge before the recovery interval of the first is completed, as was expected, then the 35% duty cycle implies that the recovery time for the 8 microsecond discharge is about 14.8 microseconds. In the present study, the recovery time for a pulse of this same duration and amplitude is approximately 13 microseconds which is in close agreement with 14.8 microseconds.

Conclusions

A summary of the conclusions and machining suggestions reached in this investigation are as follows:

1. When the coking condition is present in the gap space, the recovery times indicate that it requires the longest time interval for recovery of any electrode material combination or gap conditions tested previously. Therefore, the phenomena will be self sustaining once it starts and it is best avoided by using proper maximum duty cycle settings.

2. The coking condition occurs most frequently at the edge of the tool electrode-workpiece cavity or in an area of poor flushing. This indicates that coking is related to the gap contamination level and its probability of occurrence can be reduced by better gap flushing.

3. Recovery times during an occurrence of coking are independent of the electrode materials used since the coking growth act as the electrode.

4. The "burring" phenomena appears to be related directly to the recovery times and if the duty cycle is set according to the maximum recovery time data it can be avoided.

5. Certain electrode materials are more prone to the coking or arcing phenomena than others. Graphite or carbon electrodes are the most commonly used EDM materials that are particularly susceptible to the phenomena, but it can be avoided by using the proper duty cycle setting.

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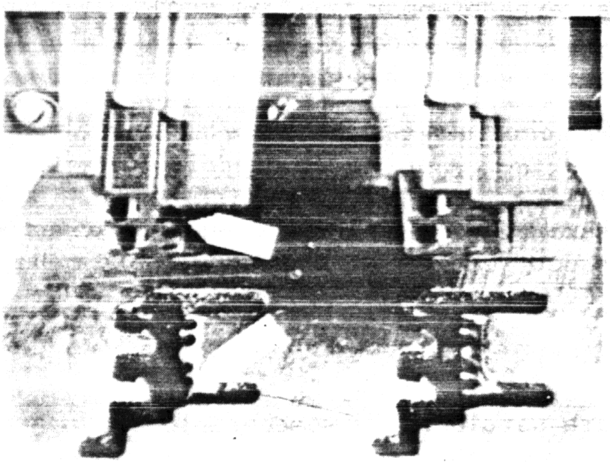


Fig. 1-Die Opening in an Aluminum Extrusion Die. The Cavities were Machined Simultaneously in a Single Operation with two 'Identical Electrodes. One Cavity developed a Carbon Growth and suffered Damage - Note the Missing Protrusion (Left Arrows) in the Left Cavity, and Tool Electrode.

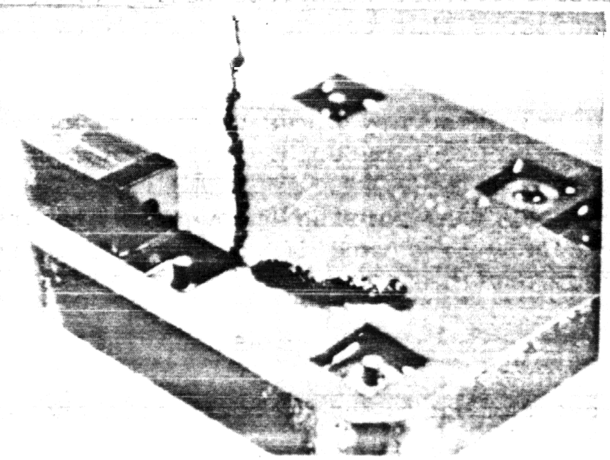


Fig. 2-Carbon Growth which Developed in a Commercial EDM Machine under Normal Operation. The Vertical Growth is Attached to the Steel Workpiece (Anode). The Carbon Growth lying Horizontal was forced attached to the Graphite Electrode (Cathode).

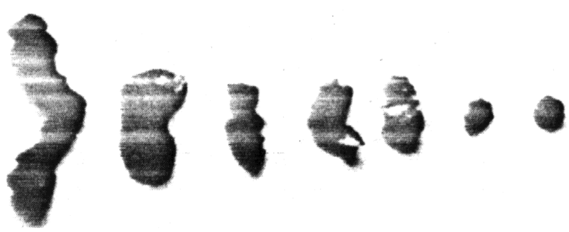


Fig. 3-Typical Coking Growths of Varying Size obtained during a Normal EDM Operation.

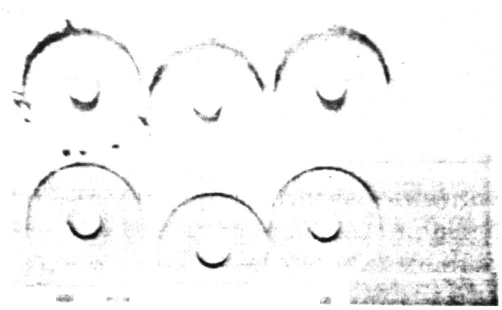
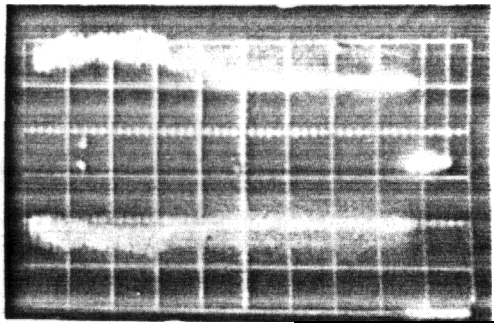


Fig. 4-Example of 'the Damage Typically found When "Burring" has taken Place on a Steel Workpiece.



a)

b)

a) Vert. 10 Volts/ Division

b)Vert. 6.66 Amps/ Division

Horizontal 5 Milliseconds/Division

Fig. 5- Oscillographs of the Machining Current and Voltage Waveforms that shows a Standard Machining Pulse converting to a Coking Pulse.

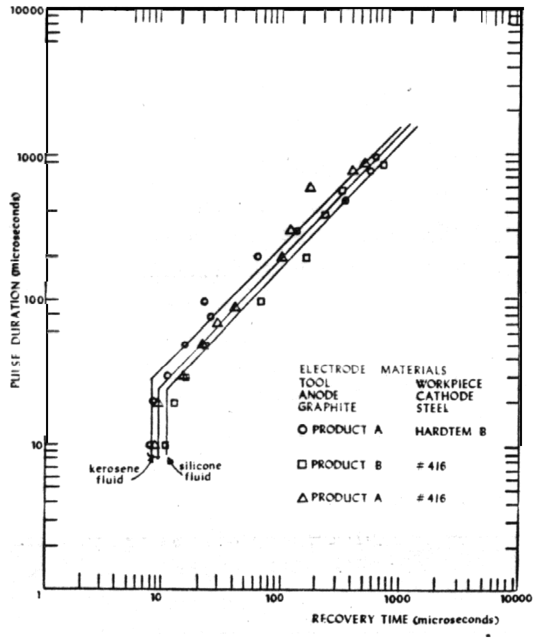


Fig. 6-Recovery Times for Two Graphite Materials as the Anode and Steel as the Cathode in the Indicated Dielectric Fluid With a Coking Condition.

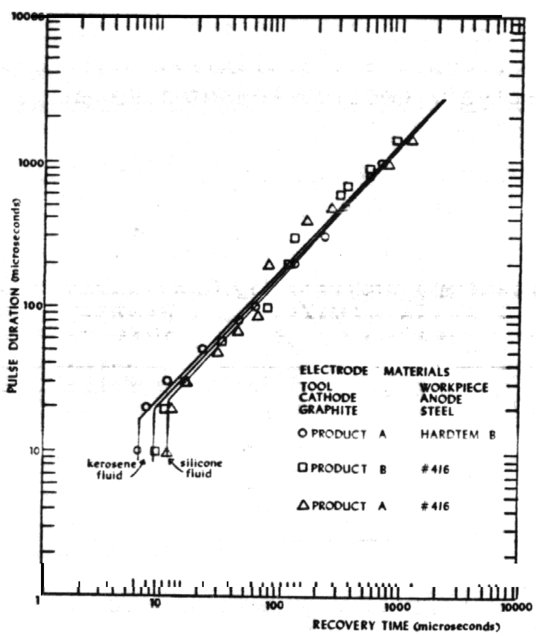


Fig. 7-Recovery Times for Two Graphite Materials as the Cathode and Steel as the Anode in the Indicated Dielectric Fluid With a Coking Condition.

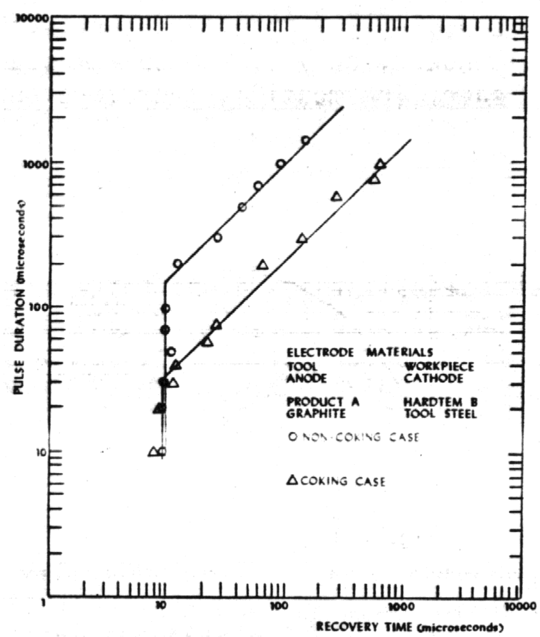


Fig. 8-Recovery Times for Product A Graphite as the Anode on Hardtem B Tool Steel as the Cathode in a Kerosene Based Dielectric Fluid with and without a Coking Condition.