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REVIEW OF LITERATURE ON MECHANISM OF ELECTROEROSION OF METALS

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INTRODUCTION AND GENERAL DISCUSSION

Many materials which have been developed in recent years have presented the engineer with difficult machining problems because of their extreme hardness and resistance to abrasion. The introduction of electroerosion techniques may, therefore, permit new applications of intrinsically hard and hardened materials, since this method may allow such materials to be formed more conveniently and economically, particularly where complex shapes are required. Moreover, this technique for grinding will result in the conservation of diamond bort, which is becoming extremely scarce.

It is possible, by means of electroerosion, to concentrate a large amount of energy onto a relatively small target, thus causing the removal of material. To provide a practical machining method, this technique must satisfy the following important requirements: first, it must be repetitive and continuous in order that a satisfactory rate of metal removal may be maintained; second, a high degree of accuracy in the finished product must be obtained; and third, the application of the process should be simple so that it can be used in the production shops and not confined to the laboratory.

The electroerosion technique is applied in three different processes, namely, Electrolytic, Electrosparking and Electroarcing.

Electrolytic Process

Electrolytic grinding is usually performed by a revolving metal-disk cathode in close proximity to anodic workpiece while an electrolyte is applied to the disk and work in the same manner as a coolant is applied to a grinding wheel and work. The method is useable for removing stock from electrically conducting bodies such as metals or metal carbides. It appears suited for removing stock from large surfaces, but its applications are limited where very small surfaces need to be ground, or for drilling of small-diameter deep holes. O. W. Storey[14] has discussed this process in detail and also the fabrication of such a cathode disk.

This process utilizes steady direct current, a highly conducting electrolyte, and relatively low voltages of less than 25 volts. It is characterized by low local heating and essentially no consumption of cathode. Here a true electrochemical action takes place in accordance with Faraday's law. With fixed current density, the rate of stock removal, in terms of volume per unit of time, is proportional to the effective area of the work exposed to electrolytic action. Cathode-anode spacing and polarization effects appear to be critical factors in the electrolytic process, particularly for shaping or finishing cemented carbides.

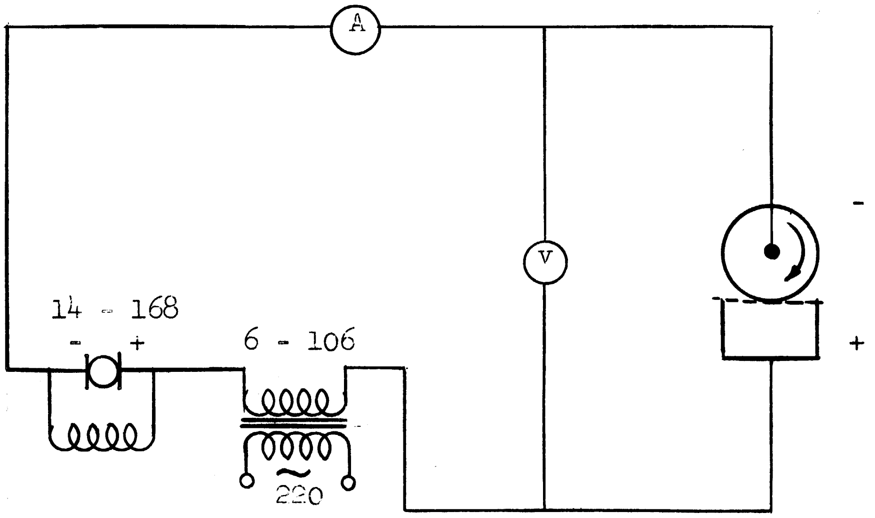

Fig. 1. Circuit Diagram for Grinding Used by L. Ya Popilov.

Electrosparking Process

In this method, stock is usually removed by making the work one of the electrodes in a properly designed circuit. Rapidly pulsed current (usually oscillatory) of the spark-discharge type is passed between the work and the other electrode in a dielectric fluid. The method is used for removing stock from electrically conducting bodies such as metals and metal carbides and is suited for forming small-diameter holes of any shape.

The removal of metal by this process, Sparcatron[15] claims, is effected by the energy liberated during a short period of time and over a very localized area, by a spark generated between an electrode and the workpiece. These two members form part of a d-c circuit, the voltage applied across the gap being of sufficient magnitude to reach the breakdown point of the dielectric medium separating them so that sparking occurs. Current supply can be obtained from a conventional d-c generator, or a rectifier unit can be employed.

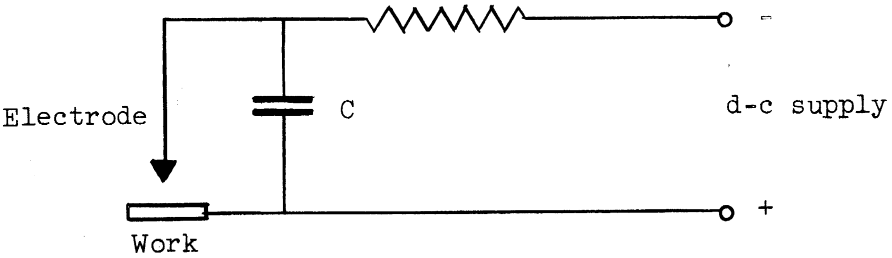

Fig. 2. Basic Circuit of Sparcatron Process.

The energy absorbed during the spark discharge is derived from the condenser C, which prevents arc formation after discharge due to the decrease in voltage across it and, consequently, across the gap between electrode and work. The cycle starts with charging of the condenser from the d-c voltage source. The condenser voltage and therefore the voltage value across the gap are initially zero but rise exponentially until the supply voltage is balanced. The spark gap is, however, such that the breakdown voltage of the dielectric medium in the gap is reached before the condenser is fully charged. The discharge is of an overdamped nature.

I. Koncz,[20] from his work carried out at the Mechanical Technological Institute in Budapest, Hungary, says the electrode periodically contacts the work and causes the condenser to discharge. The discharge takes the form of a spark at the point of contact, which is quenched by a liquid covering the component. Every spark discharge removes some of the material of the component and the electrode drills the hole. The success of this operation depends on the quenching operation, which should not permit the formation of an arc between the component and the electrode. I. Koncz[20] has not specified whether a dielectric or electrolyte should be used as the quenching liquid.

Koncz adds that the electrode requires an oscillatory and translational motion in the drilling process to make periodic contact with the work, whereas in the piercing operation by the Sparcatron process, the electrode is not given that motion. According to I. Koncz, this motion causes the electrode to contact the work when the condenser is sufficiently recharged from the previous discharge. The time for recharging the condenser is calculated by using the formula

$$E = E_o \left(1-e^{-t/RC}\right) ,$$

where E = charging voltage,
E_o= voltage of power source, and
t = the time.

Also, the inductance L of the charging circuit cannot be neglected.

To avoid oscillations when contact is made, the following relation should apply:

$$R^2 \geqslant \frac{4L}{C} \, .$$

Describing the way the material is removed from the work, E. M. Williams[19] claims that microscopic examination of the work surface gives evidence of fracture by mechanical forces. The author adds that analyses of residues from spark machining of tungsten carbides give no evidence of physical or chemical changes that might be associated with high temperatures or melting. Crystallographic studies of machined surfaces show that machined-surface temperature rises are insufficient to produce any crystal transformations. Also, the author says, electric field forces account for a major component of the erosion. The author has made some calculations to show that the stress at the bottom of the fragment, neglecting shear stresses on its sides, is of the order of 140,000 pounds per square inch, which is sufficiently in excess of the breaking strength of the material to account for fracture.

Supporting E. M. Williams, Paul Porterfield[6] says that when the spark discharge occurs, excess electrons in the electrode rush through the ionized path in the dielectric. Since opposite charges attract, electrons rushing from the electrode exert a pull on the protons of the workpiece. This force exceeds its tensile strength and causes a small particle to break away.

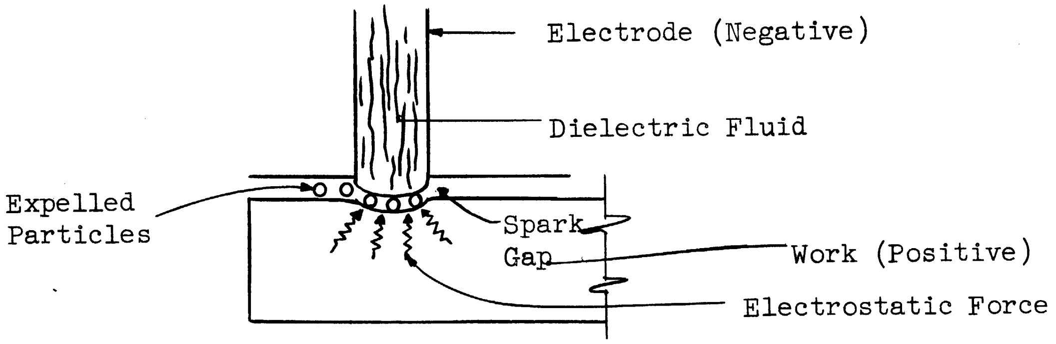

Fig. 3. Electrospark Cutting Action.

Porterfield seeks confirmation of his statements in the simple experiment of "rubbing a hard-rubber comb briskly with wool cloth and holding the comb over tiny bits of paper". Rubbing removes some electrons from the comb and causes it to attain a positive charge, so pieces of paper are attracted. When the distance is small, bits of paper will jump and cling to the comb momentarily. This force is the same force as that exerted by the electrons traveling toward the work, but the energy available from circuitry associated with "Method X" is many times greater than the forces exerted in the simple experiment. At some finite point in their path toward the work, clouds of electrons flowing from the electrode exert a force on the workpiece that exceeds its tensile strength and as a result causes a small particle to break away. The force that can be exerted on the work is a result of instantaneous current or electron flow in the spark discharge.

The electrode or tool is charged negatively and is advanced toward the work. When the distance between electrode and work is small enough, the dielectric breaks down and forms an ionized path that allows the charges to neutralize. The author concludes by saying that there is no evidence of crystal transformation or change in surface hardness.

In the article "Electronics Applied to Machining of Hard Metals", the author goes on to describe the "Sparcatron Unit" with proper electrode holder and servoelectronic system designed to maintain a constant spark gap (predetermined) between the electrode and the work.

But Sparcatron[15] engineers, describing the unit, feel that the process can be applied successfully to hardened materials as well as to those in their normal state since, although temperatures as high as 12,000°C may occur at the spark gap, there is no appreciable heating of the work. They also claim that the structure of the material is affected only to a depth of 0.0001 inch and show a photomicrograph of a typical specimen after spark erosion.

Another benefit, they say, which results from this process is a reduction in the incidence of fatigue failure due to microcracks on the surface of the work. The surface structure after spark machining is not unidirectional and comprises a series of minute pits. This type of pattern is stated to give enhanced oil retention, making the process particularly suitable for the finishing of plain bearing journals and bores of cylinders of steam and internal-combustion engines.

I. Koncz[20] has shown photomicrographs of holes drilled by spark machining and holes drills mechanically. The author points out that the boundary crystals are deformed in the mechanically drilled holes but not in the holes made by spark machining. No deep thermal effects can be detected in a spark-machined hole, and as the boundary crystals do not decrease in size, the temperature does not rise about its critical value. Concluding, the author says that the material removal of the machined component is proportional to the power taken from the condenser. The arc which may follow the discharge process is supplied by the direct-current source and is to be suppressed, as it decreases the efficiency of spark machining. Spark machining probably consists of heating the contact above the boiling point, followed by sudden disintegration; a subsequently formed arc does not increase the loss of material.

Electroarcing Process

The justification for distinguishing this method from the electrosparking process is questionable.

Cutting by the electroarcing process is performed by making the work the anode, with an arc maintained between work and cathode. The method usually utilizes pulsating direct current with a moderately conducting electrolyte such as waterglass solution. It is especially suitable for the rapid cutting of hard metals and carbides and may be faster than existing cutoff procedures. However, in a pure electroarcing process, somewhat rougher finishes are obtained.[17]

In this process, voltages of less than 25 volts are usually used. For the pure electroarcing process, the electrodischarge is initiated by contacting the electrodes and the current is carried by vaporized metal ions. High local heating is evidenced, with moderate consumption of the cathode.

Warren[1], describing "electric arc cutting of aluminum," feels that alternating current also can be used, provided arrangements are made for arc stabilization, e.g., by the superposition of the output of a spark oscillator. The principal result of the use of alternating current is a reduction in cutting speed to about one-half of its d-c value.

Talking about the mechanism of cutting in this particular case, the author says that the arc in an argon atmosphere (specially used in this arc cutting of aluminum) causes the removal of aluminum oxide and provides the heat required for melting; iron ions are emitted from the welding wire (electrode) of composition 0.18% C, 0.44% Mn, and projected in the direction of the wire feed by forces developed due to their passage through the powerful field surrounding the wire. This produces a scouring action and removes the molten aluminum. The tapered form of the wire within the depth of cut would result from such a continuous emission from the wire. The author adds that wherever a heat-affected zone has been observed, it has never exceeded 5×10^{-3} inch in depth.

I. Koncz[20] says that it has been observed in experiments where the circuit data made the formation of an arc easily possible, that the electrode loss increased but not the work loss. Furthermore, the tungsten of the electrode was deposited on the walls of the hole. This is understandable if welding, the deposition of material, is considered to be the opposite process to this one.

At this stage, it is interesting to observe the basic concept of these two processes from Mandel'Shtam and Raiskii's[10] point of view. They say that existing data reveal that this "electroerosion" is most clearly expressed in the high-voltage condensed-spark discharge and in the low-voltage arc discharge with the arc shunted by a large capacitance (arc in spark system). In the high-voltage spark discharge, the principal part of the energy absorbed by the condenser is known to be released during the so-called "arc stage" of discharge. This stage proceeds in the presence of a discharge potential of the order of several tens of volts and of a current intensity reaching several hundreds or thousands of amperes.

By reducing the potential of "charge" and by increasing the capacitance of the condenser, it is possible to obtain the same current density in a low-voltage arc discharge as in the high-voltage discharge. Thus the two types of discharge have the same electrical characteristics, and their spectra are also similar. The basic difference between the two is in the fact that in the spark discharge, due to a short duration of current impulses, the discharge channel has not enough time to widen to any considerable extent, so the current density reaches $10^5 - 10^6$ amps/cm^2; while in the arc discharge it rarely exceeds $10^2 - 10^3$ amps/cm^2. It is this property of the spark discharge that causes high temperatures (18,000-27,000°F), resulting in an excitation of "spark lines". Owing to the short duration of the discharge, very high energy evolved on the surface of the electrodes has no time to spread to any extent in the metal. This energy is transmitted to a very small surface area of metal, leading to explosive vaporization of the metal. Also, it is known that the electrode metal vaporizes in the form of luminescent jets or flares ejected with a very high velocity. The flare temperature reaches about 18,000°F. This high velocity, combined with elevated pressure, renders them capable of destroying obstacles encountered by them and especially the opposite electrode; it is this destruction which causes electrode erosion. Thus electroerosion is not directly connected with the electric discharge but is a secondary process, caused by the mechanical action of metal vapor jets produced by the discharge.

Type of Electrodes

I. Koncz[20] says that the work and the electrode were weighed after the drilling of every hole in order to determine their respective weight losses. The electrode chosen initially was made of brass, but its weight loss during drilling was very large. Most metals melted away at the same speed as brass. However, tungsten was found to be satisfactory and great care was taken to preserve metallurgical uniformity. The electrode loss is smaller when metals of lower tensile strength are drilled. Loss is higher when drilling metals which can be alloyed with tungsten, the metal of which the electrode is made. Electrode loss is higher when drilling cast iron than when drilling steel.

Mandel'Shtam and Raiskii[10] say that among the materials tested, iron, aluminum, magnesium and copper, the greatest destruction of the opposite electrode is caused by copper.

Fluids

In electrospark machining, E. M. Williams[19] says, a dielectric, commonly kerosene or transformer oil, is used. Following discharge the gap deionizes. It is probable that deionization is assisted by the liberation of hydrogen in the spark region through chemical decomposition of the dielectric fluid, such as occurs in oil circuit breakers.

Koncz[20] says that the quenching liquid used was petroleum, the high-frequency arcs being very efficiently deionized by the liquid.

Nevezhin[11] investigated the following liquid media for electrospark machining: water, suspension of kaolin in water with additions of borax and boric acid, waterglass solution (d = 1.3), and Ms oil. The author did not bother to make any distinction between dielectrics and electrolytes and did not mention the relative merits of those media.

In the electroarcing process, a moderately conducting electrolyte such as waterglass solution is used.[17]

In "Electric Arc Cutting of Aluminum", Warren[1] says, argon is used and the arc in this argon atmosphere causes the removal of the aluminum oxide and provides the heat required for melting.

Weber[13] feels that in the electromachining method, the cutting tool and work should be surrounded by an electrolyte rather than a dielectric. The author adds that sodium silicate (waterglass solution) is the best fluid, since it prevents the arcing effect, and concludes by saying that the specific gravity of the fluid has some influence on cutting.

Workpiece

The work should be an electrically conducting body. Electrode loss is smaller when metals of lower tensile strength are drilled. Koncz[20] says that spark machining is not economical on medium-hard metals. However, it becomes very advantageous from an economic standpoint, and with regard to quality of machining on very hard metals, and it is the only possible method, apart from diamond grinding, for the hardest metals.

Mention should be made of the ultrasonic process, which does not utilize current directly for stock removal and where the work need not be an electrically conducting body. In this process, as described by Raytheon Manufacturing Company,[2] the machine tool uses sound waves to drive the cutter through hard materials like steel, glass, stone, and ceramics. The device employs "magnetostrictive" principles. The present form resembles a conventional drill press. The cutting tool can be made of a relatively soft material such as cold-rolled steel and brass even to cut through hard steel and stone. The tool travels only a few thousandths of an inch each way with an abrasive between the tool and work to produce cutting. Extreme speed of motion is the key to its efficiency.

To drill an ordinary round hole, work is firmly clamped in place and the tool is lowered until it is in contact with the surface. A liquid abrasive is flowed over the work in a continuous stream. Power is turned on. The tool, vibrating at 27,000 cycles/sec, drives the abrasive particles at ultrasonic speed. These extremely small particles strike the work at 5,000 to 10,000 times their normal weight due to the acceleration which they have been given by the ultrasonic tool. This action cuts away the hard material. Such hard metals as alnico, tungsten carbide and molybdenum may be machined accurately and quickly with this tool, and it is claimed that accuracies of very high order may be maintained regardless of the material being cut. Actual tolerances are limited by the accuracy of dimension of the shaped tool, accuracy of feed, and ways of the machine.

ABSTRACT

THEORY OF ELECTRIC SPARK MACHINING

By E. M. Williams[19]

The electric spark process permits the rapid cutting of accurate and intricate shapes in such materials as sintered tungsten carbide, vitalium, titanium, and vanadium. This process is used for the finishing of hollow jet-turbine blades, turbine blade roots, etc.

In this process as described by Lazarenko and others, a succession of high-current sparks are caused to pass between a workpiece and an electrode having the shape of the hole which it is desired to pierce through the workpiece. The sparks are derived from the discharges of a capacitor shown in Fig. 4. Each spark more or less completely discharges the capacitor; following this the spark path is deionized and the capacitor is recharged from the d-c source through the charging resistance. During the process, material is removed from both electrode and workpiece and the electrode is advanced manually or automatically until the machining operation is complete. Lazarenko has shown that cutting speed is greatly increased if the electrode polarity is negative with respect to workpiece and if the gap between electrode and workpiece is immersed in a dielectric, commonly kerosene or transformer oil.

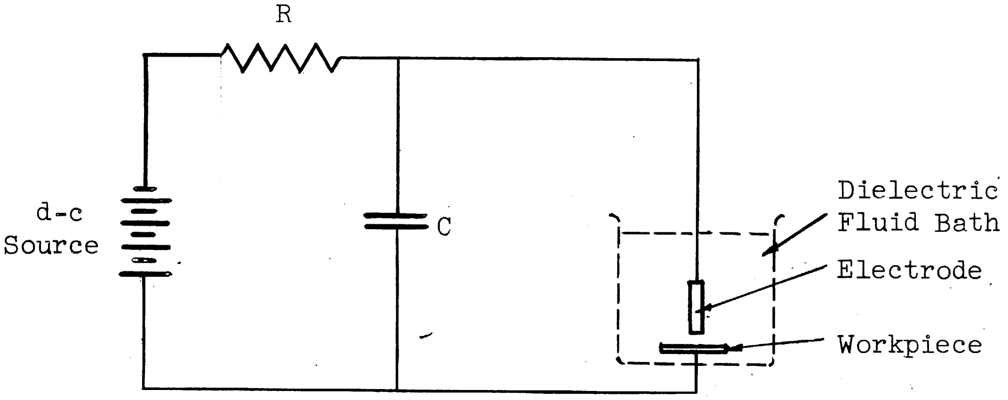

Fig. 4. Schematic Diagram of Circuit of Spark Cutting Machine Used by Lazarenko.

The physical phenomena associated with the process are as follows: The electrode, connected to the negative lead of the charged capacitor, is advanced through the dielectric toward the workpiece, which is connected to the positive head of the capacitor. When the gap between electrode and work is reduced to a value of the order of 0.003 inch per 100 volts, the dielectric breaks down and a discharge takes place. The range of working voltage in production machines is approximately 40-400 volts. The discharges are oscillatory with a range of peak currents from a few hundred to about 20,000 amperes and frequencies of 10-1000 kc. Each discharge is accompanied by explosive sounds and the evolution of light and heat; these effects are particularly pronounced at higher voltages and currents. Following the discharge, the gap deionizes. It is probable that deionization is assisted by the liberation of hydrogen in the spark region through chemical decomposition of the dielectric fluid, as in oil circuit breakers. Following deionization, the capacitor recharges and the electrode advances until a voltage is reached at which breakdown again occurs. Typical spark repetition rates range from 50 to 5000 discharges/second. The detached fragments of the workpiece and electrode material are removed by the dielectric flow resulting from the local pressures caused by explosive discharges. The duty cycle is extremely low due to the low recovery rate of capacitor voltage necessary to avoid arc formation and the time required to remove eroded metal.

The holes produced are larger than the electrode by the gap spacing corresponding to the breakdown distance associated with the peak capacitor voltage under any particular operating condition. Variations in gap due to variations in electrode and workpiece surface configurations as machining proceeds result in a rough-machined surface. For fine finishing, these effects are minimized by using low voltages and capacitance.

Spark machining is slow by comparison with conventional machining methods for soft materials; rates of material removal are of the order of 1 gram/minute. For very hard materials, this process is more economical.

Material removed by sparks of varying amplitude and fixed duration is roughly proportional to the 3/2 power of peak discharge current. Also, the gap width (corresponding to the voltage with which the capacitor is charged, as instant discharge takes place) has little effect on crater depth and area but is significant in that the crater location with respect to the electrode position becomes increasingly erratic as the gap width is increased. Operating voltage thus has an important effect on machining accuracy.

Electrode material has little effect on the dimensions of the crater produced in the work. Erosion of the electrode itself, however, varies considerably between materials and is also a function of electrode form.

Spark erosion, in which erosion is the greatest at the positive electrode, is quite different from arc cutting systems, in which greater erosion takes place at the cathode. Arc erosion is accompanied by high temperatures and melting, whereas in the spark process, microscopic examination of the workpiece surface gives evidence of fracture by mechanical forces. Analyses of residues from spark machining of sintered tungsten carbides give no evidence of physical or chemical changes that might be associated with high temperatures or melting of tungsten carbide. Machined surfaces exhibit no alteration in surface hardness. Crystallographic studies of machined surfaces of material with transformation temperatures slightly above ambient have shown that machined-surface temperature rises are insufficient to produce such crystal transformations. Thus it may be said definitely that material is removed without melting.

Electric field forces account for a major component of the erosion. These forces arise because of high current density at, about, and beneath a point on the surface of the work material and cause a correspondingly high electric-field gradient and force on the positive ions of the crystal lattice. The magnitude of the forces involved can be estimated, thus, for example, a current of 5600 amperes produced in sintered tungsten carbide a crater 0.0085 mm deep and 0.078 mm^2 in area. The peak surface current density $J_s = 5600/0.078 = 71{,}700$ amp/mm^2 or about 7,170,000 amp/cm^2. The resistivity of the tungsten carbide sample was about 28×10^{-6} ohm-cm, so that the normal component of the electric-field gradient just beneath the surface $E_s = 201$ volts/cm. The number of free electrons (equal to the number of positive ionic charges) in tungsten carbide is of the order of magnitude of the number of metal atoms. In tungsten carbide, this criterion indicates a positive charge density of 5.8×10^3 coulombs/cm^3, or in the fragment corresponding to the crater in this case a charge of 3.9×10^{-3} coulomb. The force on the fragment is thus 0.784×10^7 dynes or 17.6 pounds. This is equivalent to a stress at the bottom of the fragment, neglecting shear stresses on its sides, of 145,000 pounds/in.^{2}, which is sufficiently in excess of the breaking strength of material to account for fracture. But a larger fragment than that observed is not detached because the normal component of current density decreases below the surface due to spreading of current, which is augmented by the skin effect. Erosion of the electrode is due to (1) the oscillatory nature of the spark discharge in which the electrode becomes positive in the second half of the cycle and (2) erosion of the soft electrode material by the stream of hard workpiece particles removed from the work.

Numerous improvements in the speed and accuracy of spark-cutting machines have been effected through redesign of these machines and their associated circuits in the light of the electric-field force theory.

ABSTRACT

ON THE MECHANISM OF ELECTROEROSION OF METALS

by S. L. Mandel'Shtam and S. M. Raiskii[10]

Condenser-spark discharge is known to be accompanied by severe destruction of one or both of the electrodes. This phenomenon, known as "electroerosion", has recently begun to be widely used in metal machining operations such as "drilling". The large amount of data accumulated so far characterizes the influence of the material and shape of electrodes, constants of the discharge circuit, properties of the medium, and other influences on the extent of erosion. The physical mechanism of this phenomenon has remained unclarified up to the present time, however. Some believe in "thermal vaporization of the electrode metal", while others emphasize the "electrolytic process". An hypothesis involving the action of electrodynamic forces and a number of other suppositions have also been propounded.

Existing data reveal that this "electroerosion" is most clearly expressed in the high-voltage condensed-spark discharge and in the low-voltage arc discharge with the arc shunted by a large capacitance (arc "in spark system").

In the high-voltage spark discharge, the principal part of the energy absorbed by the condenser is known to be released during the so-called "arc stage" of discharge. This stage proceeds in the presence of a discharge potential of the order of several tens of volts and of a current intensity reaching several hundreds or thousands of amperes. By reducing the potential of "charge" and by increasing the capacitance of the condenser, it is possible to obtain the same current intensity in a low-voltage arc discharge as in the high-voltage discharge. Thus the two types of discharge have the same electrical characteristics, and their spectra are also similar. The basic difference between the two lies in the fact that in spark discharge, owing to the short duration of current impulses, the discharge channel has not enough time to widen to any considerable extent, so the current density reaches 10^5-10^6 amps/cm^2; while in the arc discharge it rarely exceeds 10^2 - 10^3 amp/cm^2. It is this property in spark discharge that causes high temperatures (18,000-27,000°F), resulting in an excitation of "spark lines". Due to the short duration of the discharge, the very high energy evolved on the surface of the electrodes has no time to spread to any extent in the metal. This energy is transmitted to a very small surface area of metal, leading to explosive vaporization of the metal. From several investigations of spark discharge it is known that the electrode metal vaporizes in the form of luminescent jets or flares ejected in a normal direction with respect to the electrode surface with a very high velocity. The trajectory of these flares need not coincide with that of the discharge channel. The flare temperature reaches about 18,000°F. This high propogation of velocity and elevated pressure render them capable of destroying obstacles encountered by them, especially the opposite electrode; it is this destruction which causes electrode erosion. Thus electroerosion is not directly connected with the electric discharge but is a secondary process, caused by the mechanical action of metal vapor jets produced by the discharge. A characteristic feature of this is the fact that the anode is destroyed more intensely than the cathode. It is also known that flares originating at the cathode are greater in intensity than those at the anode. Low current density with a large distance between the electrodes results in an "inverted corrosion", but less pronounced.

Experiment

To prove the above concepts it must be established that: (a) screening of the flares to prevent their reaching the opposite electrode also reduces destruction of that electrode, (b) destructive action of a flare on an intervening obstacle remains unchanged even after the discharge channel is partially separated from the flare, and (c) by facilitating the formation of more distinctly outlined flares, it is possible to intensify the destructive action of the flare.

Influence of "Gap Distance" and Polarity. Keeping other factors constant, bearing balls were used as electrodes. From photographs, it can be seen that the extent of erosion is considerably less with a large gap than with a small gap. In the presence of a small gap, the anode was destroyed more than the cathode. In large-gap discharge, inverted erosion took place.

The cathode was destroyed because of the formation of flare, while the center of the anode developed a projection formed by the cathode material impinging on the anode.

Influence of Electrode Shape and Material. A pointed conical electrode gave sharply outlined, long, bright flares. The cone ought to be very regular. This type of flare is just connected with the characteristics of flare formation on a sharp conical electrode. As expected, disintegration caused by a conical electrode was found to exceed that caused by a blunt electrode. Among the materials tested, iron, aluminum, magnesium, and copper, the greatest destruction of the opposite electrode is caused by copper. From pictures, it was found that flares from copper electrodes were more compact and stable than flares from the other metals tested. With sharp conical electrodes, various "gaps" were tried. With small gaps, deep craters were formed. With larger gaps, five surface injuries in the form of pits and droplets of metal were formed. Thus with the aid of a sharp copper cone and small spark gaps, it is easy to obtain the severe damage to steel objects which characterizes the "electric-spark metal cutting" method.

Screening of Flares. Since electroerosion is based on the destructive action of a flare from the opposite electrode, screening of the flare must at least appreciably reduce the destruction. To verify this, a circular quartz plate 0.5 mm in thickness was placed between the electrode subjected to destruction and the source of the flare. The edge of the plate was beveled and projected 0.1 to 0.2 mm beyond the conical apex of the electrode. Experiments showed that the destruction of the ball was negligible and was quite superficial in character, and the screening of the flare prevented destruction of the opposite electrode almost completely.

Effect of Flare Expansion and Experiments with Capillary-Encased Electrodes. The diminution of the erosive action of flares when "gap" is increased is due to expansion of the flares as they move away from the electrodes. To prevent this expansion, the diameter of the flare was artificially limited by confining a wire cathode in a capillary about 1 mm in diameter, the capillary being drilled through an insulating material. No marked effect was observed when the gap was small; the results were the same. In the next series of experiments, channel and flare were separated in space, and again the results were the same. Velocities of these flares ejected from the capillary exceed 2 km/sec. They are unstable and expand immediately after leaving the capillary. Instability of flares accompanying high-power discharge is one of their essential characteristics and does not depend on accidental variations in the conditions of the experiment.

The flares assume a different appearance when the power of the discharge is reduced by the introduction of a self-inductance; the flares become stable and acquire the form of a smooth jet. This, too, is not accidental. Such smooth, stable flares exert no erosive action.

Immersion of Electrodes in Liquids. Experiments show that discharge in water, compared with the discharge in air, produced severe destruction. Apparently the liquid confines the channel, acting as a capillary in preventing expansion of the flare and intensifying its destructive action.

Conclusions

It can be confirmed with sufficient assurance that electroerosion of metals is a secondary process caused by the destructive action of the flares on the opposite electrode. Flares capable of causing damage expand immediately after being ejected from the capillary, indicating the existence of high pressure in the flares and supercritical velocity. Flares incapable of causing damage retain jet shape (from the capillary), indicating that their velocity is subcritical. How far these velocities affect the destructive action has not been clearly understood. It is possible "cavitation" plays a role here.

There are possible cases where an "arc" not shunted by a capacitance is broken. Current density during the first 10^{-6} to 10^{-5} sec may reach values (10^5 - 10^6 amps/cm^2) characteristic of spark systems due to the formation of metallic bridges; i.e. here too, the anode may be destroyed more strongly than the cathode.

ABSTRACT

ELECTROLYTIC GRINDING OR MACHINING OF METALS[14]

The Minerals and Metals Advisory Board of the National Research Council hold that the electrolytic grinding method is particularly promising for flat offhand grinding as applied to sharpening of single-point tools and particularly to the finishing of sintered carbides. It is also well suited to sharpening of milling cutters and broaches, grinding of projectile cores and sharpening of twist drills.

In this process it is important to: (1) control the anodic action at low potentials, dissolving even the hardest metals readily, and (2) remove the metals at rates comparable to those obtained by mechanical methods.

Process

A metal-bonded diamond grinding wheel is used, but its function differs essentially from the ordinary diamond grinding in that the diamonds no longer operate on the metal or stock. They function primarily as insulating spacers between "stock anode" and the revolving nickel cathode surface in which they are anchored, and secondarily as a mild abrasive to keep the surface of the anode free of films of insulating insolubles (oxides formed when carbides are anodically dissolved). An enormous saving in cost of diamonds is realized. The diamonds used are of coarser mesh and the particle concentration has been increased considerably. This increased concentration helps in preventing intermittent contact between workpiece and cathode. With close spacing of the electrodes (0.007 inch or 0.0178 cm), a continuous stream of electrolyte is needed. The wheel speed used was 5000-6000 sfpm.

Electrolyte

The choice of salt solutions depends on the composition of the workpiece. With a highly conductive workpiece, Na salts are used generally. Na_2SiO_3can be used to help decrease edge erosion, as it forms a protective coating on adjacent surfaces, but the rate of cutting is decreased.

Fabrication of Wheel

A single layer of diamonds in a very thin adhesive film is mounted on a steel ring. A thin layer of copper is plated onto this surface, followed by Ni (say 1/8-inch). Then this composite structure is mounted on the basic wheel, steel ring being removed. The exposed Cu deposit is dissolved anodically in cyamide bath, thereby uncovering the tops of the diamonds firmly held in the underlying Ni matrix. The wheel must run very true. The electroformed Ni or Ni-Co alloy must be a low-stress deposit. A dense, tough, hard deposit is necessary to hold the diamonds securely. It should be a good conductor of electricity and highly abrasion-resistant.

Automatic Control of Voltage

To get maximum current density without causing arcing (usually 25V), an electronic unit was built into the rectifier. "In electrolytic grinding, the metal is removed at the anode substantially in accordance with Faraday's law".

Claimed Advantages

1. No stresses or strains are set up in the workpiece by grinding.

2. Because of extremely cool grinding, there are no hidden cracks.

3. A matte surface is produced, in contrast to the parallel scratches and grooves produced by normal grinding.

4. Finishes can be obtained as fine as 4 microinches provided the wheel runs true.

5. Grinding this way gives the same life for the tool as in conventional grinding.

This grinding produces a slightly rounded edge on the part of a tool being ground, i.e., the very top edge where the electrolyte first hits the tool.

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