Environmental Constituents of Electrical Discharge Machining

By

Margaret H. Cho

Submitted to the Department of Mechanical Engineering
on May 20, 2004 in Partial Fulfillment of the
Requirements for the Degree of

Bachelor of Science

at the

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ABSTRACT

Electrical Discharge Machining (EDM) is a non-traditional process that uses no mechanical forces to machine metals. It is extremely useful in machining hard materials. With the advantages EDM has to offer and its presence as a common and useable technique, along with the other machining processes available to the industrial world, there is an added strain on the environment. The scope of this thesis includes analyzing the various inputs into EDM and the resulting outputs into the environment. A simplified model is used to analyze the process. The main categories of flow scrutinized in the model are material flow and energy flow. The most hazardous effect to the environment is found in the resin interaction of the wire EDM process where depending on the type of material machined, there is a potential presence of hazardous materials. There are efforts to recycle all salvageable materials such as wire and metal wastes, but currently no accountability system exists as manufacturers are responsible for their actions.

Thesis Supervisor: Timothy G. Gutowski

Title: Professor and Associate Head of Mechanical Engineering

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1.0 Introduction

Electrical Discharge Machining (EDM) is a machining practice of metal removal by a series of rapidly reoccurring electrical discharges (spark). The sparks occur in a gap filled with dielectric fluid between a tool and workpiece. The process removes metal via electrical and thermal energy, having no mechanical contact with the workpiece. The electrical energy from the spark is converted into thermal energy, melting the workpiece at the surface.

EDM was first invented in 1943 by the Russians Lazarenkos. The Russians utilized the knowledge that when two materials have an electrical charge and a gap, a spark can be generated between the two. A spark carries in it the potential to do work due to its thermal energy. This energy is used to remove metal material by melting or vaporizing it, depending on the intensity of the spark and the nature of the material. The Lazarenkos' discovery showed promise in machining then recently developed new materials. Use of resistor capacitor tube type generators in the 1950's perpetuated intricate and complex shapes to be machined out of hardened steel in industry. Further developments in the 1960's of pulse and solid state generators reduced previous problems with electrode weak, as well as the inventions of orbiting systems in the 70's reduced the number of electrodes used to create cavities. Finally, in the 1980's a computer numeric controlled (CNC) EDM was introduced to America.

Electrical discharge machining emerged from the need to machine new hard materials in various, more complex shapes. Conventional machining processes with their high costs have made EDM a popular and prevalent solution in industry. Since EDM require no mechanical forces to machine the workpiece, any type of material can be machined, as long as it is a conductor of electricity. Electrical discharge machining has become a widely practiced nontraditional machining technique. More than 36,000 units were reportedly in use in the United States in the year 1996 by American Machinist.

1.1 Motivation for Current Work

With all the advantages EDM has to offer and its presence as a common and useable technique, it adds to the strain on the environment along with the other machining processes available to the industrial world. As technology advances and the earth's population grows, natural resources become a topic of concern, and someone must take responsibility for the use, addition and or subtraction to the environmental.

1.2 Existing Data on EDM

There have been numerous studies on process of electrical discharge machining. Many of these studies have focused on effects variables in the process. For instance: gap space between anode and cathode, the erosion characteristics, heat transfer in process, etc. While this data is useful in studying and improving the process, they do not address the environmental effects and strain it can cause.

1.3 Variables in EDM

EDM incorporate a number of different variables. Table 1 describes both the dependent and independent variable in the process.

Dependent	**Independent**
Work Erosion Rate	Dielectric Fluid
Tool Erosion Rate	Flow rate of dielectric
Surface finish	Temperature of dielectric
Surface Damage	Tooling Material
Definition (fillet)	Workpiece Material
Arc Voltage	Polarity
Machiniability	Frequency
Interelectrode distance	Pulse Shape (square, etc)
Overcut	Arc Current
Material Transfer	Design and geometry of piece
Feed Rate	Maximum Voltage

Table 1. Dependent and independent variables in EDM

EDM units utilize sophisticated software that set certain parameters according to machining applications, material properties, geometry and design, and the desired surface finish or machining time.

1.4 Scope of Present Work

The specific questions which I strive to address pertain to the environmental strain from this process, specifically, the energy for specific operation, and the handling of material wastes from the process. To analyze such environmental strains, first the EDM process is outlined in detail to examine where environmental strains arise.

2.0 Background

The process of electrical discharge machining has made significant developments in the past decade with the emergence of applied technology seen in computer numeric controlled (CNC) codes as well as the level of sophistication of software in computers. Manufacturers of EDM have burst out with a variety of EDM units with more features than many home computers. Yet, independent of the features of specific units, the concept of process is consistent. Here, it is described in brief. Subsequent sections will expound on the variables listed in Table 1.

2.1 System Model

The scope of this thesis' research included analyzing the various inputs into EDM and the resulting outputs into the environment. To do such an analysis, a model was made for the process. Some parameters were chosen to be neglected due to their complex nature or relatively small magnitude within the scope of the system. The main categories of flow scrutinized in the model are material flow and energy flow. Figure 1 models the EDM process as it pertains to the system.

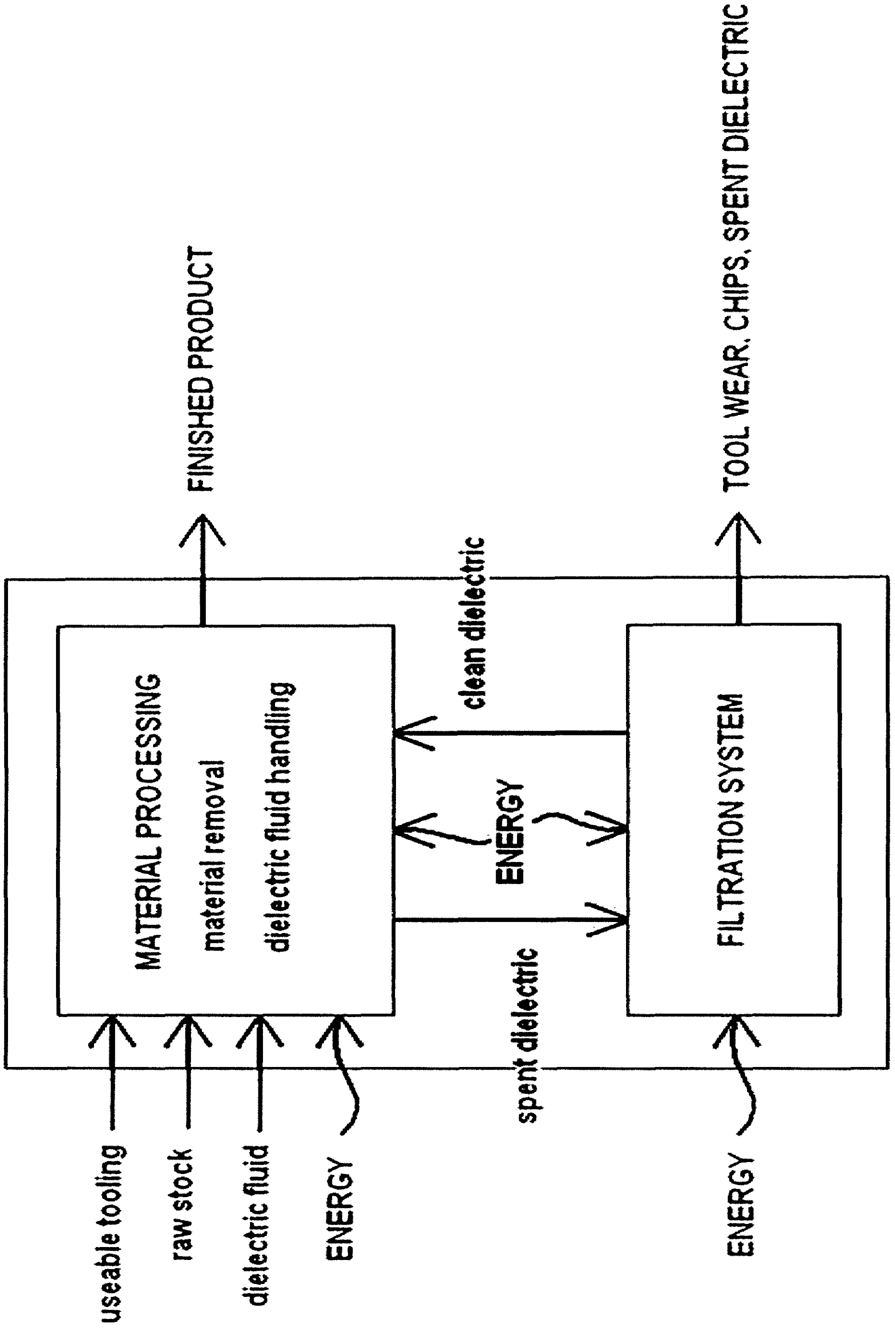

Figure 1. Model of EDM process inputs and outputs

The system inputs include the raw materials which include workpiece and the electrode tool. The dielectric fluid which flows in the system is cleaned when passed through the filter, then recycled and circulated via pump back into the system. The direct results of EDM is a finished machined product and system wastes which include the chips from both the raw material and the tooling, and some dielectric fluid not circulated back into the system. To take the inputs at the start of the process, namely point one, to the end of the process, point two, energy is used to drive the system.

A description of the electrical discharge machine and its functionality are described in the following section.

2.2 Process Mechanics

Overview

Die-sinker EDM is what is usually implied when one refers to the EDM process. The die-sinker EDM process will be used to illustrate the theory and description of electrical discharge machining. The apparatus setup incorporates an electrode and workpiece which house electrical discharges. Here, an electrical charge is sent from the electrode tool to create a charge between itself and the workpiece. As the charge builds, a spark is created. Figure 2 shows this.

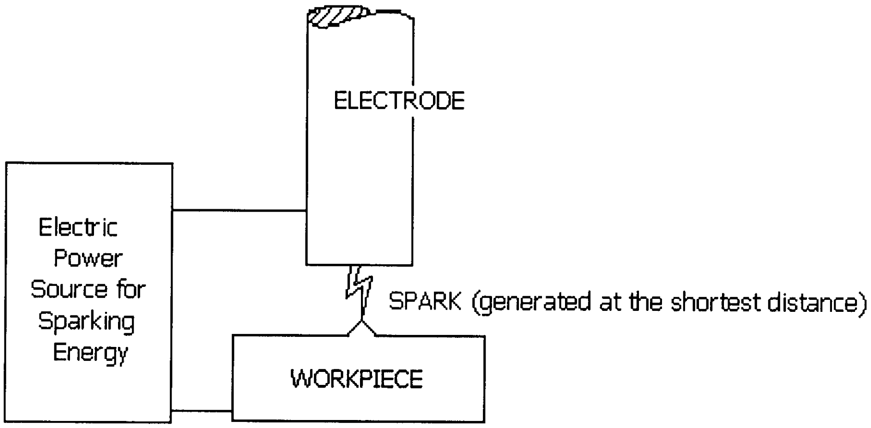

Figure 2. Spark generated in electrical discharge machining

This spark is generated in the space between the electrode and the workpiece, resulting in a mirror image of the tool in the workpiece. A dielectric fluid, in the case of die-sinker EDMs is typically a hydrocarbon based oil, is used to make a path for the discharges as the fluid ionizes in the space between the tool and workpiece. The spark occurs where the tool and workpiece are physically closest; it is at this point that the fluid ionizes, allowing for discharge. The discharge creates a small difference between gap distances, therefore that localized location is less likely to be subject to a spark until the sites around that point have been machined to the same level The discharge creates a temperature high enough to melt the workpiece and create a "chip" which is then carried away from the work area by the dielectric fluid. Figure 3 depicts the described process.

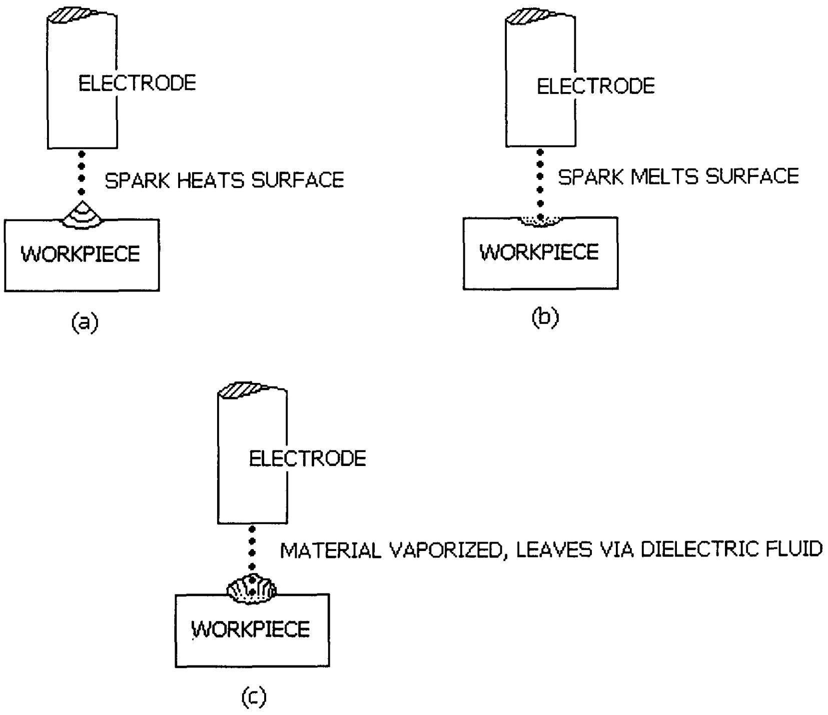

Figure 3. Work surface conditions during a single spark

These sparks occur at a frequency and duration determined by the user depending on the workpiece dimensions as well as material properties.

Electrical Control

Erle Shobert III describes the complexities of a seemingly simple operation:

> "It (EDM) involves breakdown of the spark gap through the oil, the quick formation of an electrical arc between the workpiece and the electrode, and the removal of material from both. Included in this cycle are the timing of the arc to control the surface finish, and the cutoff of the current and voltage by the power supply. The rate of cutting depends on the current, the duty cycle, the frequency, and the direction of the current. The surface finish also depends upon these factors as well as on the electrode material."

There are a lot of factors which go into the generation of a spark which results in the desired finished piece of work. The first circuit to accomplish the wearing away of metal was developed by the Russians Lazarenkos. Figure 4 is a diagram of the relaxation or RC circuit which is the basis of electrical discharge machining.

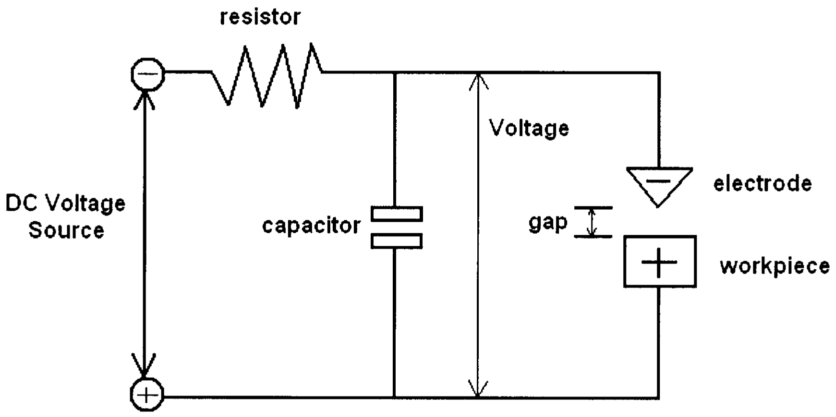

Figure 4. RC circuit which governs EDM

To requirements to run an EDM unit vary with the function and settings under which it is operating. For the CNC EDM, the powerhouse of the operation is a pulse generator power supply. "The reason is rather simple; only with the use of a pulse generator and orbiting of the electrode can wear be maintained at a rate of less than 1%" (Piotrowski, 26). A typical waveform is depicted in Figure 5.

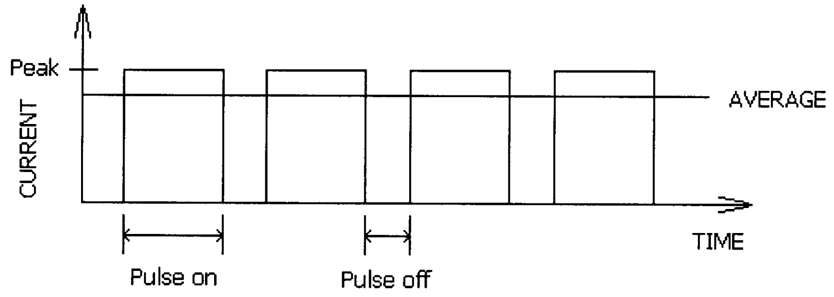

Figure 5. Typical waveform of pulse generator.

The ratio of the time that the pulse is "on" and the pulse is "off" yield what is called the duty cycle. Figure 6 shows the typical voltage and current characteristics of the pulse generator.

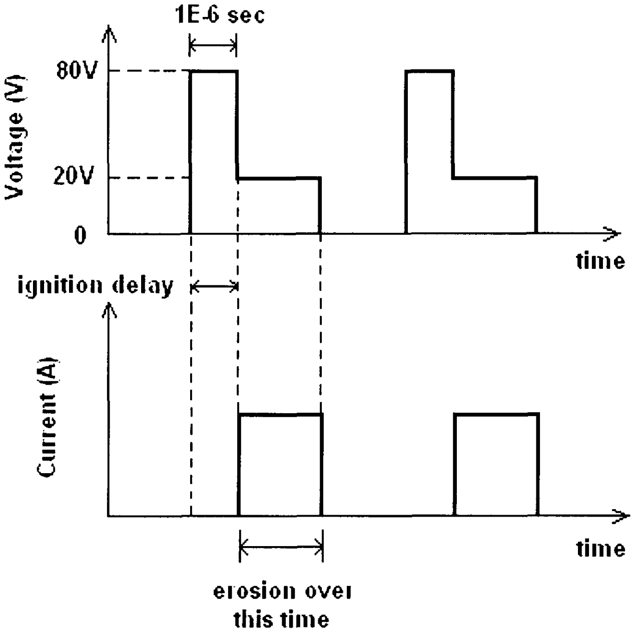

Figure 6. Typical Voltage and Current for pulse generator.

2.3 Process Inputs

Using the proposed model, the inputs into the system are identified as measurable quantities such as energy, tooling, raw stock, and dielectric fluid.

Energy Input

The source of power for the EDM operations is the pulse generator power supply. The EDM power supply unit also operates with adaptive control. Adaptive control is more or less a feedback loop; as information is fed to the controller from the workpiece, the controller is able to change its inputs thus affecting the workpiece.

Most units require a minimum of AC 220V, but are available with other voltages like 380, 400, or 440V. Generators for the EDM unit come in a variety of sizes, specific to the size of work being machined as well as the frequency of use. Generator max currents range depending on how industrial the application. It was recommended that job shop type applications, appropriate max currents ranged from 50-150 Amps, whereas the more industrial sized applications call for greater max currents like 300-600 Amps. EDM manufacturers are such that different generators can be bundled with smaller machines.

Material Input

There are many different types of materials associated with EDM. Certain metals are desired for their ease of machining, their hardness, or any of their other material properties. Table 2 lists the some commonly used of these materials and notes their advantages and disadvantages with respect to EDM.

Material	Description	Advantages	Disadvantages
Brass	Used to form EDM wire and small tube electrodes.	-easy to machine -can be die cast or extruded	-does not wear as well as copper or tungsten
Carbide	Compound of a metal/metalloid and carbon. Also known as hard metals: -tungsten carbide (WC) -titanium carbide (TiC) -tantalum carbide (TaC)	-high hardness -high melting point -increased toughness compared to pure carbide or ceramic	
Copper	-commonly used for wire EDM applications	-good wear resistance -good for machining tungsten carbide -useful for fine finish applications	-difficult to machine compared to brass or graphite -expensive
Copper Graphite		-good conductivity -high strength -thin sections easily machined	-expensive
Copper Tungsten	Composites of tungsten and copper produced using powder metallurgy processes	-deep slots under poor flushing conditions	-expensive
Graphite	Most commonly used electrode. Form of carbon with anisotropic hexagonal crystal structure. Non-metallic element with high sublimation temperature	-good machinability -low wear -low cost -high resistivity to high temperature arcs -fine grain has low erosion and wear	-fine grain costly
Molybdenum	Used to make small hole EDM electrodes and specialized wire EDM applications. Refractory metal	-good strength -high melting point -high arc erosion resistance -low wear	
Silver Tungsten	Made of composites of tungsten and copper using powder metallurgy processes	-useful for making deep slots under poor flushing conditions	-expensive
Tellurium Copper	Similar to brass, better than pure copper	-fine finish applications	
Tungsten	Refractory material with high temperature strength. Most used for grinding	-high melting point -high arc erosion resistance -low wear	-brittle -low conductivity
Tungsten Carbide	Compound of tungsten metal and carbon usually with a metal binder	-high hardness -low wear -relatively high toughness	

Table 2. Common Materials in EDM

The use of a certain material is more or less application specific. A number of different factors will come into play when choosing materials for the electrode including surface finish, time constraints (higher or lower duty cycle capabilities and tradeoffs between machine time and material capacity), and tool complexity. To reiterate one of the advantages of EDM is the ability to machine any metal which conducts electricity. But EDM's ability to machine much harder materials makes it a great tool for non-traditional metals as found in Table 2.

2.4 Process Outputs

Surface Finish

The desired end result of EDM is to produce a finished product with specified dimensions, and a certain surface finish. Along with the finished piece, there are peripheral products of the process.

Chips

The material that is removed from the workpiece consists of two parts. Once the workpiece has been melted or vaporized, a primary "chip" forms from the vapor. The "chip" forms between the pulses of the sparking and is removed from the work area by the dielectric fluid. The sizes of such chip-like spheres of material range from 2 to 100 μm. During the machining process, a secondary chip is formed. In the case of machining above the work surface, this secondary chip solidifies and remains on the work surface creating a burr. Once the tool has submerged below the entrance surface though, secondary chips are removed conjointly with primary chips, being flushed out by the flow of the dielectric fluid. On the surface, secondary chips will affect the finish and will vary depending on the magnitude of the spark as well as the work material. Figure 7 depicts the two chips formed and their respective locations in the process.

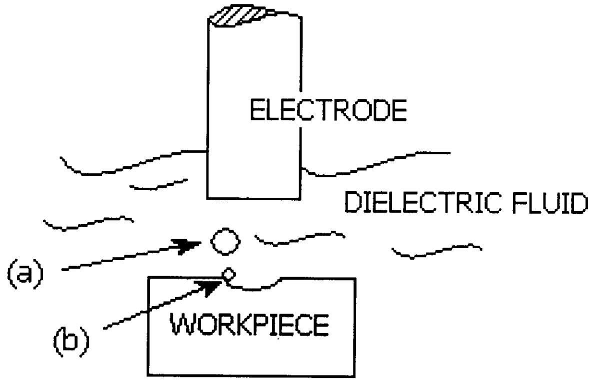

Figure 7. Chip formation detail. (a) primary chip removed by dielectric fluid. (b) secondary chip which solidifies on surface.

The chips are carried away in the dielectric fluid and are captured and collected in a filter as the dielectric fluid is cycled back into the system.

Tool Wear

The chips collected in the filter come not only from the workpiece, but can also originate from the metal of the electrode. It is noted that tool wear is an issue and perhaps the greatest disadvantage in the otherwise celebrated process. As the spark melts the workpiece, so too is the tool affected. Figure 8 shows the affected area of the electrode.

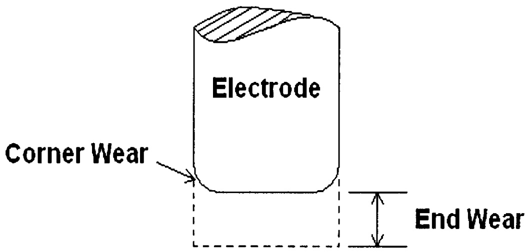

Figure 8. End wear of electrode

The electrode life cycle depends on its ability to resist wearing at the most vulnerable points depending on the electrode's geometry. Wear will vary depending on variables such as the applied voltage, current, chosen material, etc.

In die-sinking EDM, the workpiece is made in the mirrored image of the tool. Consequently, however complex the desired shape, an equally complex shaped electrode is required. As the part is machined, electrode wear is accounted for to ensure that the final shape of the machined part is accurate to design and specification. This accounting for tool wear is more difficult for more complex shapes. Additionally, producing such intricate electrodes in production is also difficult, taking much time, and having high cost. The solution to this problem is to employ simple shaped electrodes whether machining relatively simple or machining complex shapes. Machining using a simple shaped electrode has is lower cost and has a shorter fabrication time. Also, with the simple shape, the discharge can be localized at the end of the electrode.

Tool wear of the electrode can be defined in a number of different ways.

$$ToolWear = \frac{work\_material\_removed}{tool\_material\_removed} \tag{1}$$

where both the work and tool material removed can be consistently measured in mass or volume. Typically, the ratio of tool wear ranges between 1.0 to 100, depending on the material chosen for the electrode and the material being machined, the applied voltage, and the current. "EDM-equipment manufacturers publish charts of typical metal-removal rates and percentages of electrode wear for specific machine settings and workpiece and electrode materials when using EDM at optimum conditions. Shops then use these same parameters to measure actual metal-removal rates and percent of electrode wear to compare how close to the benchmark their machine is performing." (Bates, American Machinist).

Dielectric Fluid

The dielectric fluid performs three main functions in the EDM process. By definition, a dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic fields. If the flow of current between opposite electric charge poles is kept to a minimum while the electrostatic lines of flux are not impeded or interrupted, an electrostatic field can store energy. Therefore, the first purpose of the dielectric fluid is to insulate the gap between the electrode and workpiece, conducting the sparks by breaking down at the appropriate applied voltages respectively. During ionization occurs, the dielectric facilitates the transfer of electrical discharge in the gap, but between the pulses of charge, the dielectric allows for non-conductive activity. Secondarily, the dielectric flushes out the chips from the machined area, and finally, the dielectric facilitates heat transfer away from the tool and the workpiece by acting as a coolant. The oils should have a high density and a high viscosity.

The best fit for such materials have been fulfilled by liquid hydrocarbons such as paraffin or light transformer oils. Research developments have yielded broad alternatives ranging from highly refined petroleum based oils to synthetic fluids. While dielectric oils of the past were more odious in smell and irritating to the human skin, the newer generation of oils maintains high dielectric strength and constant viscosity, but also to take into consideration the effects on the environment and humans.

Various dielectric fluids can affect the accuracy of EDM cuts as well as the surface finish. "More often than not, the choice of fluid or dielectric is solely to blame for inadequate finish and decreased production." (Vollaro 83). The dielectric is helpful in eliminating DC arcing which is continuous flow of electrical current between an electrode and workplace and can damage either or both pieces.

2.5 Wire EDM

Wire EDM, like the sinker EDM machines the workpiece by thermal energy from electric charges between the electrode wire and the workpiece. The workpiece is fed continuously past the wire to cut out the desired shape. In the wire EDM case, the dielectric fluid used is typically deionized water. Figure 9 depicts the wire EDM schematic.

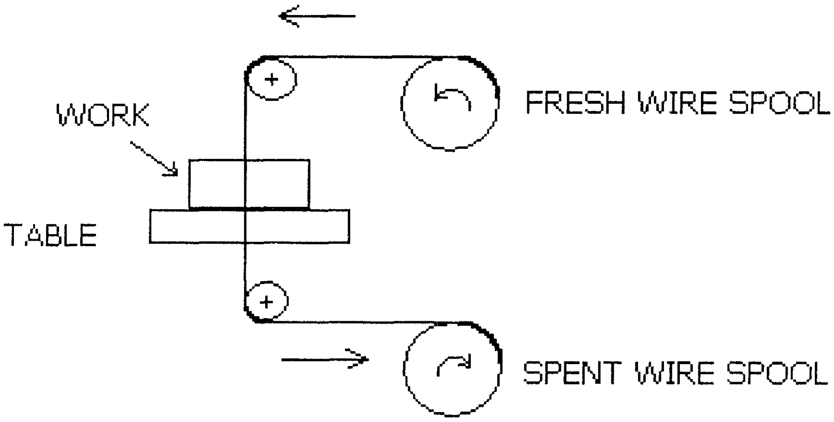

Figure 9. Wire EDM schematic

Similar to the die-sinker EDM process, there exists an undercut from the sparking occurring between the wire and the workpiece. The wire is constantly fed by a series of motors and pulleys until it is removed entirely from the system into a receptacle to be removed as waste. Figure 10 shows an illustration of the wire EDM's pulleys and wire path.

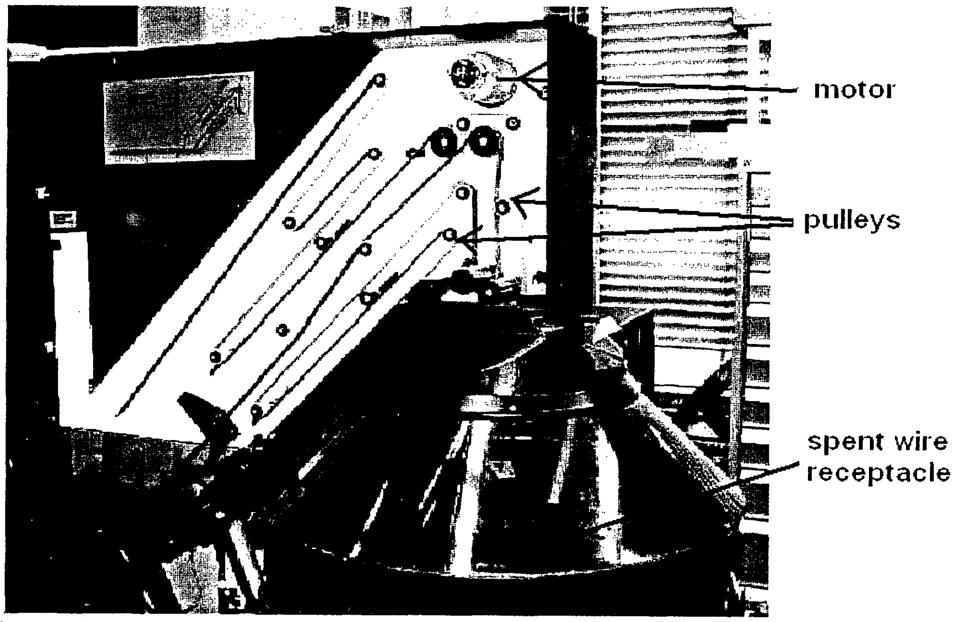

Figure 10. Wire EDM pulley system.

The wire EDM operates under the same principles as the die-sinker EDM, but manifests itself in a slightly different manner. In this case, the wire is the electrode, but since it is constantly moving, the wire does not need to have the EDM wear or arc erosion resistance because new wire is constantly being fed during the machining process. The ideal wire electrode material for this process has three important criteria: high conductivity; high mechanical strength; and ideal spark and flush characteristics. Like most variables in machining, there is no wire that meets all these criteria optimally, but all three factors are interrelated and interdependent. These ideals are supported by materials with relatively low melting point and high vapor pressure rating. Table 3 lists typical wires used in wire EDM applications.

Material	**Description**	**Advantages**	**Disadvantages**
Copper	-original material for wire EDM	-high conductivity	-low tensile strength -high melting point -low vapor pressure rating
Brass	-copper zinc alloy	-low melting point -high vapor pressure rating -wide ranges of tensile strengths and hardness	-poor conductivity
Coated	-brass or copper core Zinc coated -nicknamed “speed wire”	-high metal removal rate	-expensive
Fine Wires (Moly & Tungsten)	-Diameters from 0.001”-0.004”	-small diameter for high precision applications	-limited conductivity -poor for thick work -slow cutting rate

Table 3. Various materials for wire EDM.

Another clear difference between wire EDM and die-sinker EDM is the use of deionized water as a dielectric fluid as opposed to hydrocarbon based oils in the latter application. The deionized water fills a bath which houses the location of the “cut” and the bath fills and empties similar to a waterjet bed.

Finally, the resin is an additional substance in the deionized water not found in the die-sinker application. The purpose of the resin is to control resistivity of the dielectric by removing the dissolved solids.

3.0 Constituent Analysis

3.1 Energy

Observations were conducted using the Charmilles Robofil 1020SI wire EDM. This is a small sample of types of wire EDM, but appropriate for examining the inputs and outputs of the EDM system model. The workpiece was 6.35mm thick aluminum cut in deionized water with standard Copper wire with 0.2286 mm diameter. The Charmilles wire EDM utilizes software such that sets appropriate feed rates, max voltage, current, and roughing and finish cuts according to the material of the workpiece.

Material Removal Rate

Tests were run to change pertinent variables and the feed rates were recorded for each variable changed. In the case of the Charmilles Robofil 1020SI wire EDM and the cutting application, the feed rate was a function of the average voltage, the duration of the pulse, the duration of the short pulse, and the duration of time between pulses.

One variable of note was the average voltage, which is in the same scale as the machining voltage. The average voltage acts on the wire straightness during finishing and surface finishing cuts. The voltage was variable from 30 volts to 60 volts, with the max voltage being constant at 80 volts. Figure 11 shows the relationship between the average voltage and the material removal rate.

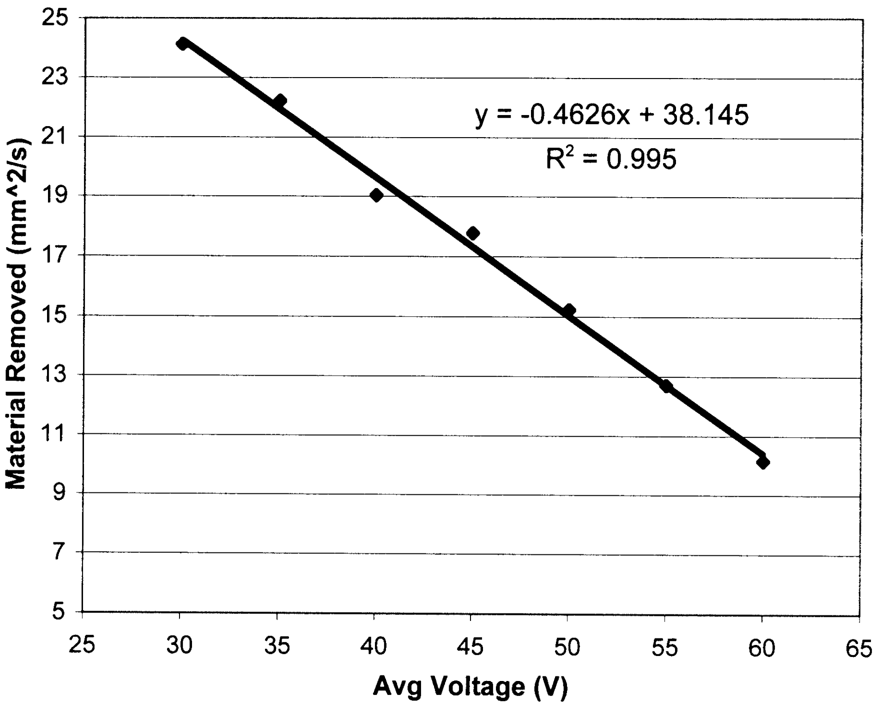

Figure 11. Material Removal Rate (mm^2/s) as function of Average Voltage (V).

The voltage input affected the feed rate linearly, thus affecting the material removal rate as well. For greater average voltages, the removal rate decreased. This can be also seen in the difference between rough and finish cuts. Since rough cuts apply lower average voltages, the cut can occur more rapidly, whereas with finish cuts, the material removal rate is slower since a higher voltage is being applied to the workpiece.

In the case of the pulse duration itself, there was another linear correlation observed. The pulse duration, or time of actual cutting, was adjustable from 0.2 to 2.0 microseconds. All other variables were kept constant while the pulse duration was changed and feed rate recorded. Figure 12 shows the relationship between the pulse duration and the material removal rate.

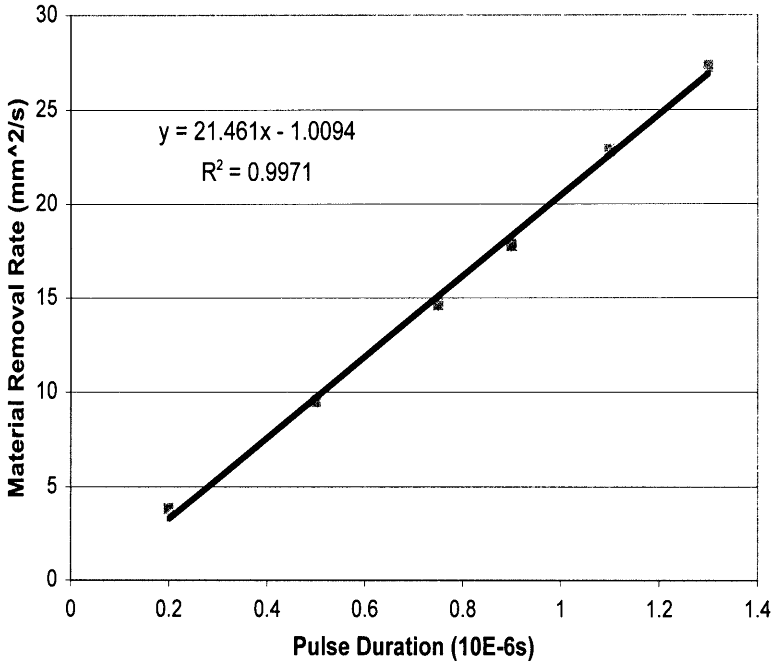

Figure 12. Material removal Rate (mm^2/s) as function of Pulse Duration (μs).

The relationship between the two is linear. This is supported when reverting to the theory, where erosion occurs over the pulse duration (Figure 6).

Besides changing the time of erosion, the time in between erosion was a variable as well. The increase of time between pulses causes visible change in the machining as the sparks were more intermitted and the surface finish was far rougher the longer the time between pulses. Figure 13 shows the material removal rate as a function of time between pulses.

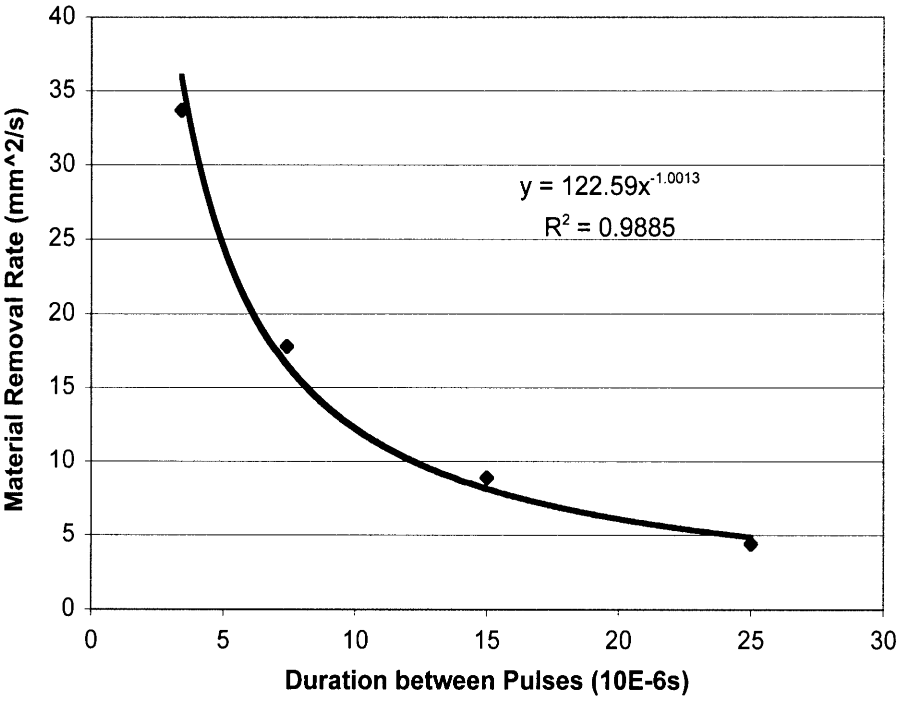

Figure 13. Material Removal Rate (mm^2/s) as function of Time between Pulses (μs).

The increase in time between pulsing resulted in a far smaller rate of material removal. This is analogous to the governing theory.

Power Requirements

Most EDM machines were power rated for industrial usages. Accessibility for hands-on testing was limited, but information was collected based on manufacturing specifications. The table below lists various sized EDM units made by Mitsubishi Electric, one of the top manufacturers of EDM machines. Table 4 lists the various models' power consumption specifications and current outputs.

Machine Unit	Workpiece Dimensions (W x D x H) [mm]	Workpiece Weight [kg]	Power Reqs [kVA]	Generators Peak Current [A]	Average operating current [A]
Mitsubishi wire FA10	800x600x215	500	13.5	50	NA
Mitsubishi wire FA20	1050x800x295	1500	13.5	50	NA
Mitsubishi wire FA30	1300x1000x345	3000	13.5	50	NA
Mitsubishi sinker EA8	740x470x150	550	6.8	80	60
Mitsubishi sinker EA12	900x550x250	700	8.2/15.6	80/120	60/100
Mitsubishi sinker EA22	1050x700x300	1,000	9.0/16.5	80/120/270	60/100/200
Mitsubishi sinker EA30	1230x800x350	2,000	15.5/26.0	80/120/270	60/100/200

Table 4. Various EDM Units, Power requirements, and Max Currents for Mitsubishi

The values in the table with more than one value represent modular additions to the power supply, in which case, the peak current drawn will be different than standard models.

Figure 14 graphically represents the total input that small sized units (<0.1995 m^3) versus mid-sized units (<0.2205 m^3) and large units can output for peak currents for Mitsubishi EDM models.

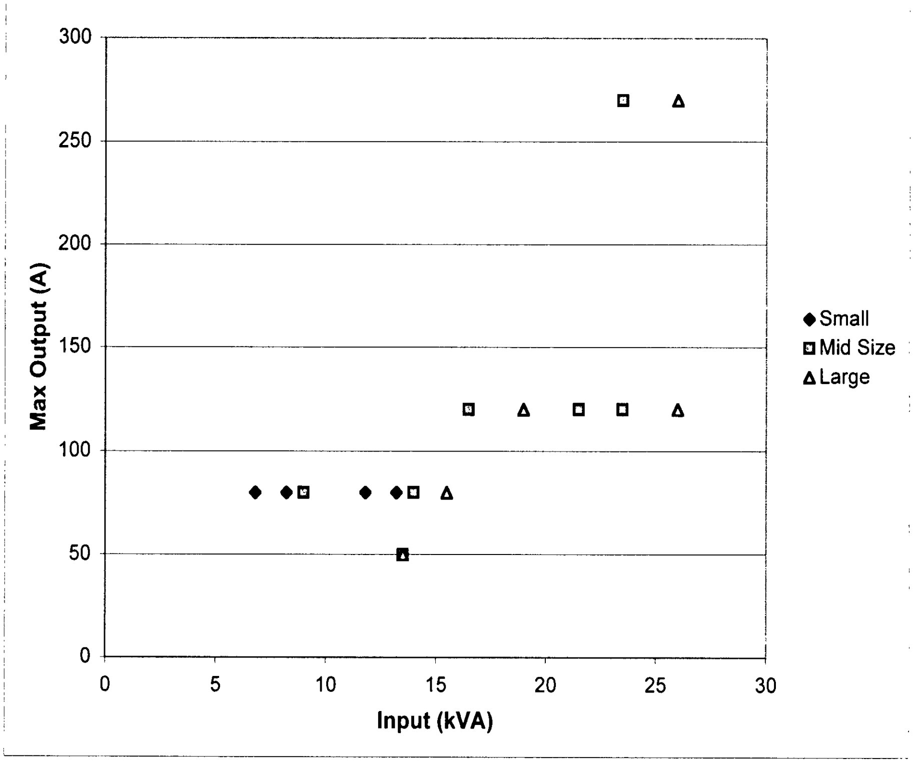

Figure 14. Scatter plot of Peak Currents (A) per Power Inputs (kVA).

It should be noted that identical max current outputs can be generated from different power inputs. This is due to the manufacturers offering a variety of options to the customer depending on the site's power availability as well as the site's specific need.

To experimentally find the amount of operational energy in the case of the Charmilles Robofil 1020SI wire EDM, an oscilloscope was used to record the current between the anode and the cathode during operation. Ohm's Law states that

$$V = iR \tag{2}$$

where V voltage is in watts, current i is in amps, and resistance R is in Ohms. Knowing two of the variables in the equation will yield the third. The resistance between the anode and cathode was measured at approximately 200 Ohms. As the different variables were changed, data was recorded for the corresponding current changes. Again applying Ohm's Law

$$P = Vi \tag{3}$$

where P is power in Watts. Substituting Equation 2 into 3 yields

$$P = i^2 R \tag{4}$$

where *P* is again power in Watts. Using the data collected from the oscilloscope, Table 5 presents the power consumed (kVA) and the material removal rate for changes in sparking time and short pulse times.

Feed Rate (mm/s)	**Material Removal Rate (mm^2/s)**	**Current (A)**	**Average Voltage (V)**	**Power Consumed (kVA)**
0.6	3.81	12	45	540
0.7	4.45	10	45	450
1.4	8.89	15	45	675
2.0	12.7	16	45	720
2.8	17.8	20	45	900
3.3	20.96	27	45	1215
4.3	27.3	35	45	1575
5.3	33.66	37	45	1665

Table 5. Data collection for Power Consumption (kVA).

Figure 15 depicts the power consumption (kVA) as a function of the material removal rate for input changes of sparking time and short pulse time.

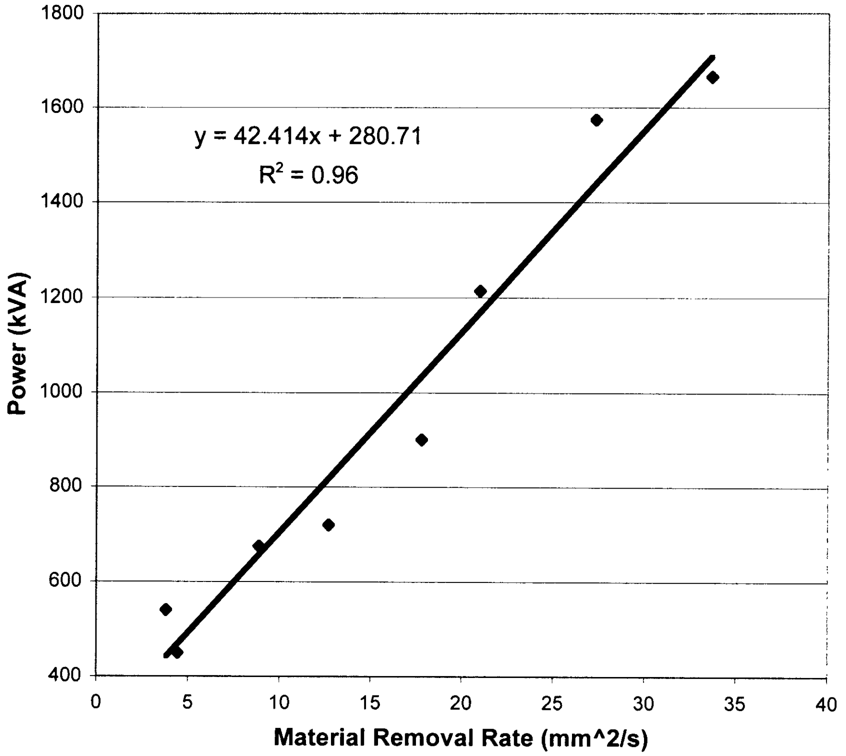

Figure 15. Power consumed during process

The total power consumed for the process of cutting the 6.35mm thick piece of aluminum was linearly related to the material removed from the process. The greater the material removal rate, the more power was consumed. It is noted that in the tests run, the max power consumed was approximately 7400 kVA, which is approximately 2.25 horsepower.

3.2 Waste Products

Filter Wastes

The amount of waste in the EDM process is dependent on the design of the part, the material, as well as the machine settings. In the part machined on the wire EDM, the chip content collected in the filter was about 90% of the mass removed from the workpiece. The disparity in the mass removed and the mass found in the filter can be attributed to the vaporization of the workpiece material in the dielectric. In large scale production, the filter is disposed by incineration, but in smaller jobs, the filter is disposed of in its entirety to landfills as standard waste. Depending on the state and its legislation, this practice may be acceptable. According to an article in the March/April 2003 edition of EDM Today, EBBCO, an EDM wire and filter recycling company recognize the wire for EDM as being the highest operational cost with filters coming in second. EBBCO offers insight on how companies are weighing costs and proper disposal of filters:

> "With many parts of the country putting disposal restrictions on used filters, and many shops trying to attain ISO 14000 status, the need for lowering filter and disposal costs is a priority. ISO 14000 is the environmental management standards, similar to the ISO 9000 quality standards that thousands of organizations have registered for, to meet the growing demands from customers. This requires companies to properly document disposal practices, and to investigate alternative means of disposal, recycling wherever possible. In most parts of the country, used EDM filters go straight into dumpsters and then into local landfills. In many parts of the country they are in violation of local landfill guidelines. However, no one is monitoring the dumpster. Large manufacturing facilities have environmental staffs to protect the company, and to make sure that all waste water, oils, coolants, filters, etc. get sent to the proper waste handling facilities. This is obviously much different from small Tool & Die or Mold Shops that just throw everything into the dumpster behind the shop...Most small EDM shops know that used Wire EDM Filters should not go to the local landfills because of the chromium, lead, nickel (cutting tool steel) and copper (brass wire)."

Although the filters may contain trace elements of hazardous materials, many companies can justify disposal of filters into landfills since they are not producing "large scale amounts" of waste. But if many companies are operating under these same assumptions, there can be a potentially significant amount of hazardous waste entering the environment. And since there is no tracking of how companies may or may not be handling these wastes, it is unclear as to the exact number of pounds of waste deposited into landfills each year.

Resin Disposal

Disposal of the spent wire EDM filters vary depending on the facility in which the machine is operating. It seems as though most large scale manufacturing facilities rely heavily on outsourcing of filter disposal, but this cannot be verified with all sites. Also, it seemed as though the larger the scale of operation, the more accessible the information. Some companies maintained contracts with their filter suppliers where the manufacturer would return the spent filters upon shipment of new ones. The filter companies who participated in this exchange would dispose of paper filters by incinerating them, then rely on hazardous waste suppliers to remove and handle the waste thereafter.

The main components of the filter waste include used dielectric, water with machined particles, lubricating oil, used deionized resins, and other materials subject to wear such as the wire and tooling. The purpose of resin is to control the resistivity of the dielectric fluid, in the case of wire EDM, deionized water, by removing the dissolved solids. It accomplishes this by removing the metal ions and exchanging them for hydrogen and oxygen, which then combine to make water. Resin is the main culprit in potential environmental hazards. Depending on the results of a leachate test, the resin from the filters can be determined to be hazardous waste. Much of the Environmental Protection Agency's regulations are state regulated and determined not on a national scale. The leachate test determines if the resin is hazardous by passing mildly acidic water through a set amount of resin. That water is then tested for the eight metals on the EPA's federally mandated list which are listed in Table 6.

EPA Hazardous Waste ID	Material	Acceptable Amount (ppm)
9004	Arsenic	5.0
D005	Barium	100.0
D006	Cadmium	1.0
D007	Chrome	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0
Optional by State	Copper	Determined by State
Optional by State	Zinc	Determined by State

Table 6. EPA list of Hazardous Metals

If the test yields results less than EPA's regulation limits, the resin can be disposed of as any other solid waste. However, if the resin does not pass the EPA's regulation standards, the material must be handled according to EPA specifics. The EPA's formal policy is: "Under RCRA, hazardous wastes are prohibited from land disposal unless they meet treatment standards established by EPA" (40 CFR Part 268).

In large scale manufacturing, there exist centers that handle the disposal and handling of resin and potential hazardous wastes. The procedure which one of the leaders in resin recycling, Ameriwater, describes it as: "The waste water is treated so that it solidifies the contaminants into a filter cake. The filter cake is manifested to a metal recovery facility where the metals are removed from the waste and recaptured for re-use." From interviews with Ameriwater, the liquid used to flush any of the particles is neutralized and recycled back into the system.

Spent Wire

Another waste produced in wire EDM production is the spent wire. The wire, is not classified as a hazardous waste, and depending on the unit it is either reeled onto a spool, or gathered to be chopped up for disposal as waste. Some EDM units have the option of wire choppers as an installed feature on the unit. According to interviews, many high volume manufacturers outsource their recycling. Since the brass is recyclable, metal scrappers are willing to pay EDM manufacturers for the spent brass or copper. The named price changes the market price. In smaller job shops and lower volume manufacturing, the used wire is amassed and disposed of into landfills. Some wire suppliers provide removal services for their customers. This consists of exchanging spent wire for new spools of wire.

4.0 Discussion

Innocuous Constituents

Much of the inputs and outputs of the EDM process are fairly innocuous to the environment. When the materials which the EDM encompass are machined, the resulting part has no effect on the environment. The materials prior to machining need no special handling or care beyond what is standard industrial practice for metal handling. The energy required to run the EDM unit is no greater than what comparable machining units draw. Unit designs are made to ensure that acoustic emissions are not harmful to the environment and humans around the machinery. EDM production is popularly viewed in positive light (Department Of Energy 1999 Pollution Prevention Report) since the scrap pieces are considered clean, reusable, and free of oil when compared to other scrap generated from alternative machining practices.

The wire which is either disposed of by metal scrappers or suppliers is recycled and can reenter the EDM systems after reprocessing. The filters which are disposed of and incinerated do not affect the environment significantly since they are not stored in landfills.

Harmful Constituents

There are some potentially severe effects of EDM on the environment, most prominently the effects of the hazardous materials from the filters. The biggest contributor of hazardous material is directed from the resin in the wire EDM process where the resin has potential to affect the dielectric fluid. The main differentiator whether or not the resin is hazardous depends greatly on the material machined in the wire EDM unit. For instance, if only aluminum is machined, there is no hazard as aluminum is not on the EPA's list. However, if tool steel is cut with nickel or chrome, there is a potential hazard problem. A safeguard against hazardous contamination to the environment is to have the resin used in production shipped to facilities who can properly handle such materials. This recycler employs a strong acid and caustic to remove the metal ions, leaving a residue which is the hazardous waste. The recycler is licensed to generate hazardous waste and have it disposed of according to laws and regulations. If the resin is properly handled, then no negative environmental effects should surface. But it is not guaranteed that all users of wire EDM and resins will follow such practices. Currently, since there is no regulation on the disposal of filters, wire, or any byproduct of EDM, it is the responsibility of the EDM user to properly handle and dispose of the wastes in a responsible manner.

5.0 Recommendations

The limitations of this study include a coarse simplification of the EDM system. There are many details within the process which offer more information to the effects and stress onto the environment.

Due to restricted resources, testing of the EDM parameters was limited. In terms of energy testing, ideally, a number of machines of diverse sizes would be tested. Harder materials with greater dimensions would be helpful in generating data. Also, there was no safe nor effective method to test the draw of current, or power from peripheral unit components such as servo motors, filtering pumps or wire feeders.

For future testing of waste management, effects of different wires should be examined as certain wires, namely nickel and chrome, are potential sources of hazardous waste.

Finally, a national survey of the top 100 EDM manufacturers or regional leaders would give a general sense of how much hazardous waste from EDM is disposed of in landfills. Most large scale manufacturers, due to their sheer size and productivity, must hire outside suppliers to dispose of machining waste, but most small scale companies interviewed stated that their wastes were handled within the company in a proper and responsible fashion according to the type of material being machined. This data may be impossible to attain, but theoretically, national statistics could be achieved.

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