EXPERIMENTAL INVESTIGATION OF BRONZE-ALUMINA - COMPOSITE MATERIAL CUTTING BY WIRE CUT EDM

[1] B.Karthick , [2] P.Sweetlin , [3] M.Thiagarajan
[1,2,3] Department of Mechanical Engineering, CMS College of Engineering and Technology, Coimbatore-641 032, TamilNadu, India.

Abstract
Wire cut electrical discharge machining (WCEDM) extensively used in machining of conductive materials when precision of prime importance. Rough cutting operation in WCEDM is treated as challenging one because improvement of more than one machining performance measures viz. metal removal rate (MRR) surface finish (SF) and cutting width (kerf) are sought to obtain a precision work. Using Taguchi's parameter design significant machining parameters affecting the performance measures are identified as discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow.

It has been observed that a combination of factor for optimization of each performance measure is difficult. In this study, the relationship between control factor and responses like MRR, SF and kerf are established by means of nonlinear regression analysis, resulting in a valid mathematical method. Finally, genetic algorithm, a popular evolutionary approach, is employed to optimize the wire cut electrical discharge machining processwith multiple objectives. This study demonstrates that the WCEDM process parameters can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously.

This works present an investigation on the optimization of machining parameters in WCEDM of Bronze-Alumina MMC (Metal Matrix Composite).

The main objective is to find the optimum cutting parameters to achieving a low value of Surface roughness and high value of material removal rate (MRR).

INTRODUCTION

Additional the growth of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. However, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such complicated to machine materials. WCEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness.

Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface.

WCEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WCEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining.

The wire-cut process uses water as its dielectric fluid, controlling its resistivity and other electrical properties with filters and de-ionizer units. The water flushes the cut debris away from the cutting zone. Flushing is an important factor in determining the maximum feed rate for a given material thickness.

Along with tighter tolerances, multi axis EDM wire-cutting machining center have added features such as multi heads for cutting two parts at the same time, controls for preventing wire breakage, automatic self-threading features in case of wire breakage, and programmable machining strategies to optimize the operation.

Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process.

. WIRE EDM:

Wire EDM (Vertical EDM's kid brother), is not the new kid on the block. It was introduced in the late 1960s', and has revolutionized the tool and die, mold, and metal working industries. It is probably the most exciting and diversified machine tool developed for this industry in the last fifty years, and has numerous advantages to offer.

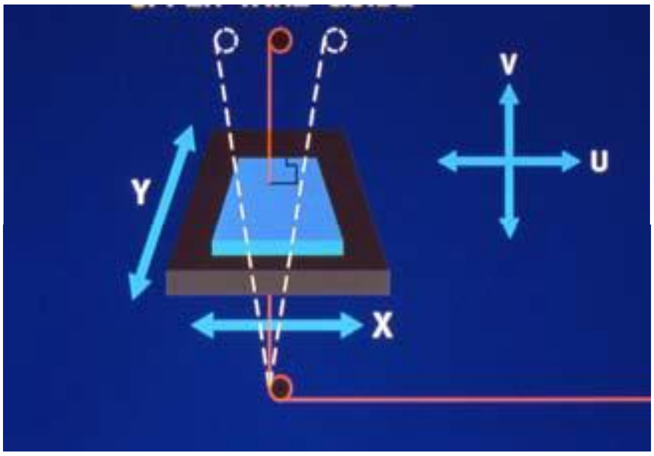
It can machine anything that is electrically conductive regardless of the hardness, from relatively common materials such as tool steel, aluminum, copper, and graphite, to exotic space-age alloys including hastaloy, waspaloy, inconel, titanium, carbide, polycrystalline diamond compacts and conductive ceramics. The wire does not touch the work piece, so there is no physical pressure imparted on the work piece compared to grinding wheels and milling cutters. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the work piece.

The accuracy, surface finish and time required to complete a job is extremely predictable, making it much easier to quote, EDM leaves a totally random pattern on the surface as compared to tooling marks left by milling cutters and grinding wheels. The EDM process leaves no residual burrs on the work piece, which reduces or eliminates the need for subsequent finishing operations.

Wire EDM also gives designers more latitude in designing dies, and management more control of manufacturing, since the machining is completed automatically. Parts that have complex geometry and tolerances don't require you to rely on different skill levels or multiple equipment. Substantial increases in productivity are achieved since the machining is untended, allowing operators to do work in other areas. Most machines run overnight in a"lights-out" environment. Long jobs are cut overnight, or over the weekend, while shorter jobs are scheduled during the day. Most work pieces come off the machine as a finished part,without the need for secondary operations. It's a one-step process.

MACHINE:

Wire EDM's are manufactured in various sizes and styles of flush or submerged type machines to fit the needs of the consumer. Large scale EDM's can handle work pieces weighing over ten thousand pounds and can cut over twenty inches thick. Automatic Wire Threaders (AWT) are usually standard equipment on most models. In addition to the X-Y table travels, wire EDM's have U / V travels for providing the movement to cut tapers. Most machines can cut tapers of 20-30 degrees depending on work piece thickness.



The system consists of aCNC control, power supply with anti-electrolysis circuitry, automatic wire threading, handheld pendant, programmable Z-axis, water chiller and filtration system.

MAJOR COMPONENTS:

A Wire EDM system is comprised of four major components.

(1) **Computerized Numerical Control (CNC)**

Think of this as “The Brains.”

(2) **Power Supply**

Provides energy to the spark.Think of this as “The Muscle.”

(3) **Mechanical Section**

Worktable, work stand, taper unit, and wire drive mechanism.(This is the actual machine tool.)Think of this as “The Body.”

(4) **Dielectric System**

The water reservoir where filtration, condition of the water resistivity/conductivity)and temperature of the water is provided and maintained. Think of this as “The Nourishment.”

We'll look at each of these components in more detail, but first let’s look at how wire EDM works.

PRINCIPLE OF WIRE ELECTRICAL DISCHARGE MACHINING:

The Spark Theory on a wire EDM is basically the same as that of the vertical EDM process. In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (the electrode) and the work piece. High frequency pulses of alternating or direct current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid (water).

Many sparks can be observed at one time. This is because actual discharges can occur more than one hundred thousand times per second, with discharge sparks lasting in the range of 1/1,000,000 of a second or less. The volume of metal removed during this short period of spark discharge depends on the desired cutting speed and the surface finish required.

The heat of each electrical spark, estimated at around 15,000° to 21,000° Fahrenheit,erodes away a tiny bit of material that is vaporized and melted from the work piece.(Some of the wire material is also eroded away) These particles (chips) are flushed away from the cut with a stream of de-ionized water through the top and bottom flushing nozzles.The water also prevents heat build-up in the work piece. Without this cooling, thermal expansion of the part would affect size and positional accuracy. Keep in mind that it is the ON and OFF time of the spark that is repeated over and over that removes material, not just the flow of electric current.

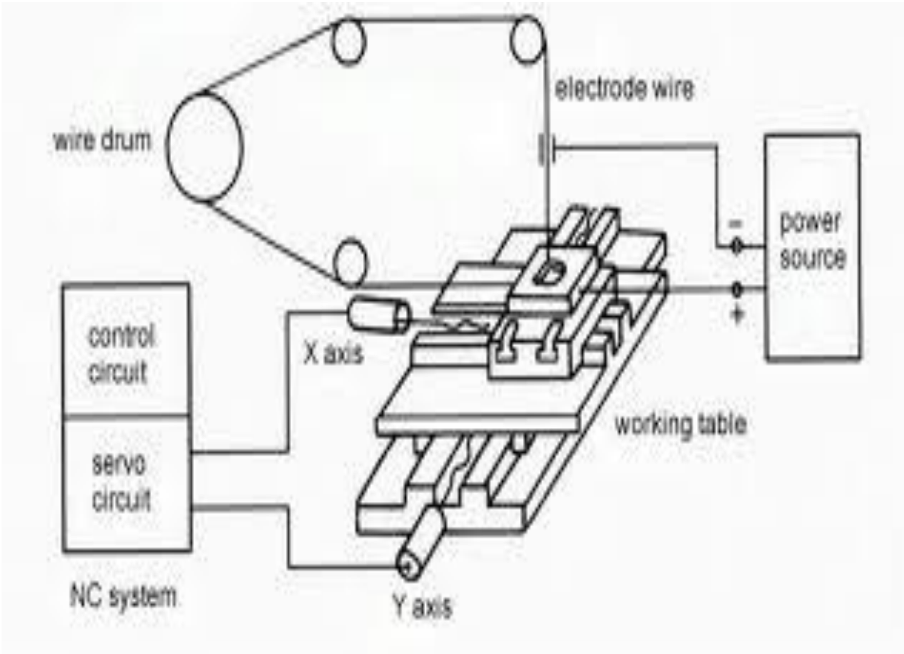


Fig (A)

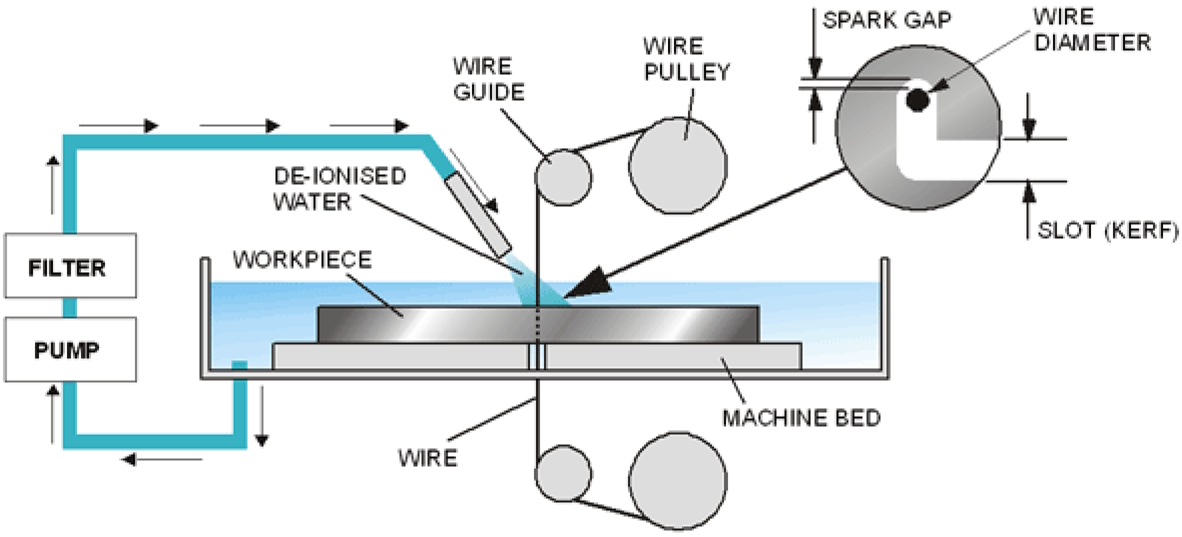


Fig (B)

STARTING A CUT FROM THE EDGE OF A WORKPIECE:

When starting a cut from the edge of a work piece, cutting a form tool, slicing a tube or bar stock, or starting a cut from a large diameter start hole, is a slower process without submerged machining capabilities. There is a greater risk of breaking a wire if the flush is not set properly or if too much power is used. This condition is greatly reduced when cutting the part submerged.

Interrupted Flush

When parts with existing openings, slots or cross holes in them must be cut, conventional flushing produces air pockets and results in reduced performance or wire breaks. Submerged machining provides stable cutting of these parts.

IRREGULAR SHAPES AND SURFACES

When it is not possible to have the flushing nozzles close to the top or bottom of the work piece, splash flush machines may require constant adjustment of the top and bottom flush. When machining submerged, you can adjust the flush once and forget it.

Users of Wire EDM

Parts made with the wire EDM process are used for machining conductive materials for medicine, chemical, electronics, oil and gas, die and mold, fabrication, construction, automotive, aeronautics, space—virtually any place where electrically conductive materials are utilized.

Benefits of Wire EDM

A**. Production Runs**

Because of the new generation of high-speed wire EDM machines, manufacturer sin creasingly are discovering that wire EDM produces many parts more conomically than conventional machining. See Figure 3:1 and 2. An additional benefit with wire EDM is that close tolerances can be held without additional cost and without burrs.

B. Various Shapes and Sizes

With this new technology, any contour and varying tapers can be machined precisely. Extremely thin sections can be made because the wire electrode never contacts the material being cut.EDM is a non-contact, force-free, metal-removing process which eliminates cutting stress and resultant mechanical distortion.

C. Accuracy and Finishes

The wire path is controlled by a CNC computer-generated program with part accuracies up to +/- .0001″□(.0025 mm), and some machines achieve surface finishes well below .037 Ra µm. Dowel holes can be produced with wire EDM to be either press or slip fit. See Figure 3:4 where precision cams were ED Med.

Machining after Wire EDM

To avoid cutting with nozzles off the work piece, it is sometimes more economical to do machining after, rather than before the EDM process. This is particularly true with shallow recesses Often parts are stacked to reduce costs. When parts have intricate dimensions, stacking may be difficult if parts have been previously machined.

Pre-Machining Non-Complicated Shapes

It is not always necessary to EDM the entire part. Sometimes pre-machining can reduce costs Wire EDM is an extremely efficient method to machine parts. However, costs can be further reduced by understanding this unique process of cutting metal. In the next chapter, we will be discussing the advantages of wire EDM in tool and die making. Understanding this process can result in substantial savings in producing stamping dies.

Material Removal Rate (MRR)

The mean cutting speed data (Cs) was observed directly from the computer monitor, which was attached to the machine tool. Generally, during this process the wire diameter is kept constant. Therefore, the width of cut (W) remains constant. Therefore, the MRR for the WEDM operation is calculated using Eq. 3 which is shown below: MRR = Cs X L -- (3) Where Cs = cutting speed in mm/mint. L = thickness of the material in mm.

Surface Roughness measurement

It was measured on Subtronic-10 surface tester giving Ra value in microns. Ra is measured along four different lines on the surface and the average value is considered for further analysis.

Selection of cutting parameters

Eight machining parameters were selected as control factors, one parameter has two levels and seven parameters have three levels, denoted by 1, 2, and 3. The experimental design was based on L18 orthogonal array based on Taguchi method. Minitab 15 software was used for graphical analysis of the obtained data.

PROPERTIES OF WCEDM:

1. Composition
2. High dimensional precision
3. Stable mechanical performance
4. High surface quality
5. High cutting speed

INTRODUCTION TO COMPOSITE MATERIALS:

A composite material consists of two phases. It consists of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement or reinforcing material whereas the continuous phase is termed as the matrix. The matrix is usually more ductile and less hard. It holds the dispersed phase and shares a load with it.

Matrix is composed of any of the three basic material type i.e. polymers, metals or ceramics. The matrix forms the bulk form or the part or product. The secondary phase embedded in the matrix is a discontinuous phase. It is usually harder and stronger than the continuous phase. It servers to strengthen the composites and improves the overall mechanical properties of the matrix.

Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent.

The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross-sanctioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites.

CLASSIFICATION OF COMPOSITES

Composite materials can be broadly classified into three groups on the basis of matrix material. They are:

- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)

- Polymer Matrix Composites (PMC)

Metal Matrix Composites

Metal Matrix Composites have many advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion. Because of these attributes metal matrix composites are under consideration for wide range of applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

Ceramic Matrix Composites

One of the main objectives in producing ceramic matrix composites is to increase the toughness. Naturally, it is hoped and indeed often found that there is a concomitant improvement in strength and stiffness of ceramic matrix composites.

Polymer Matrix Composites

Most commonly used matrix materials are polymeric. The reason for this is twofold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn't require high temperature. Also equipment's required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications. Composites are used because overall properties of the composites are superior to those of the individual components for example polymer/ceramic. Composites have a greater modulus than the polymer component but aren't as brittle as ceramics.

ALUMINUM BRONZE COMPOSITE MATERIAL:

The Bronze – Alumina (Al2O3) alloy is an Metal Matrix Composite (MMC) of interest in several applications like bearing sleeve, piston and cylinder liners etc.,

The reinforcement used in this MMC makes it difficult to machine using traditional technique. Wire Cut Electric Discharge Machine (WCEDM) seems to be a viable option to machine.

Aluminum bronze is very useful in a great number of engineering structures with a variety of the alloy finding applications in different industries (CDA, 1986). According to ISO 428 specifications, most categories of aluminum bronze contain 4-10 wt.%aluminum in addition to other alloying agents such as iron, nickel, manganese and silicon in varying proportions. The relatively higher strength of aluminum bronze compared with other copper alloys makes it suitable for the production of forgings, plates, sheet, extruded rods and sections (Pisarek, 2007). Its excellent corrosion resistance property recommends it as an important engineering material for highly stressed components in corrosive environments. The alloy is available both in wrought and cast forms and is readily weldable and fabricated into components such as pipes and pressure vessels. Despite these desirable characteristics most aluminum bronze exhibit deficient responses in certain critical applications such as in sub-sea weapons ejection systems, aircraft landing component and power plant facility. The need to overcome obvious performance limitations in aluminum bronze is imperative to meet today.

1. ALUMINUM BRONZE MATERIAL

EXPERIMENTAL PROCEDURE

The materials used comprised of aluminum bronze (ASTM B505 specification with chemical composition as presented in Table 1) and iron-oxide granules (mill scale). The aluminum bronze sample was obtained from NIGALEX (A company engaged in extrusion of different aluminum profiles) while the iron oxide granules was supplied by African Steel (Producers of hot rolled mild steel bars used for concrete reinforcement). Aluminum bronze is a special type of bronze in which aluminum is the main alloying element as against the conventional bronze. The mill scale was sieved to remove tramps and other hard lumps usually associated with mill scale to obtain smooth (homogenous) stream of particles. Further sieving of the mill scale was carried out to obtain 170-250µm fine particle size. Melting of the composite matrix material entailed that aluminum bronze having 8.5-10 wt.% was placed in a crucible pot and charged into a pit furnace to be heated until molten. Then, measured proportions of fine mill scale at 2, 4, 6, 8 and 10 wt.% were added to the molten aluminum bronze and stirred thoroughly using a long stainless steel tong. The molten mixes were homogenized at 1100oC for 10 minutes and then cast in prepared metal molds.

TAGUCHI METHOD

The quality engineering method proposed by Taguchi is commonly known as the Taguchi method or Taguchi approach. This approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. In other words, the Taguchi approach is a form of DOE with special application (8). The concept of the Taguchi method is that the parameter design is performed to reduce the sources of variation on the quality characteristics of product, and reach a target of process robustness Taguchi designs experiments using specially constructed tables known as "orthogonal array"(OA). It utilizes the orthogonal arrays from experimental design theory to study a large number of variables with a small number of experiments (9). This technique helps to study effect of many factors (variables) on the desired quality characteristic most reasonably. By studying the effect of individual factors on the results, the best factor combination can be determined. The standardized Taguchi-based experimental design used in this study is an L18 orthogonal array.

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