Current Research trends on Wire Electrodes for Wire Electrical Discharge Machining

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Abstract—*Electrical discharge machining (EDM) with a travelling wire electrode has become one of the most dynamic fields in metal working. Manufacturing advances in Electrical discharge machining (EDM) wires have directly contributed to increased cutting speed and dimensional accuracy. This paper focuses on the developments of EDM wire from copper to brass and from brass to various coated wire, which has helped make wire EDM machining, the method of choice for high-speed production as well as applications requiring improved contour accuracy and improved surface finishes. Some of the characteristics of high performance wire electrodes have been presented, which significantly increase the wire electrical discharge machining productivity.*

Key words – *Brass wire electrodes, Coated wires, Brass, Machining productivity*

1. INTRODUCTION

Wire electrical discharge machining (WEDM) is an indispensable machining technique for producing complicated cutouts through difficult to machine metals without using high cost grinding or expensive formed tools [1]. As for the wire electrical discharge machine, demand is increasing for high- speed cutting and high-precision machining for the purpose of improving the productivity of the molds and also for achieving high quality in machining workpieces. Wires used in wire electrical discharge machining are the core of the system. Brass wire electrode is used extensively as a tool for WEDM. However, along with the recent diversification in applications of manufacturing fields, demand is expanding for a wire electrode with performance superior to the conventional brass wire electrode. These electrodes in use are generally zinc coated wire with a copper/brass alloy or steel core, the brass containing either a small amount of Cr, or a high concentration of Zn. At present, the concern of EDM users is to shorten the machining time of products [2]. A new high performance EDM wire would be expected to provide both high speed cutting and improved accuracy. This paper focuses on the developments of new type of wire electrodes for high speed and high precision machinability, their various properties and discharge machining performance.

2. WIRE ELECTRICAL DISCHARGE MACHINING

Fig.1 shows a model for WEDM (Wire Electrical discharge machining). The electrical discharge occur intermittently (in a pulse-like manner) between an electrode wire and a work piece through a processing liquid so as to cut the work piece in a desired configuration. A pulse voltage is applied between the wire electrode and workpiece in the processing fluid to melt the surface of the workpiece by the thermal energy of an arc discharge, while at the same time removing machining dust through a vaporizing explosion and recirculation of the processing fluid. The residue resulting from the melting and/or vaporization of a small increment (volume) of the surface of both the workpiece and the EDM wire electrode is contained in gaseous envelope (plasma).The plasma eventually collapses under the pressure of the dielectric fluid. The liquid and the vapor phases created by the melting and/or vaporization of material are quenched by the dielectric fluid to form solid debris. This process is repeated at nanosecond interval along the length of the wire in cutting zone.

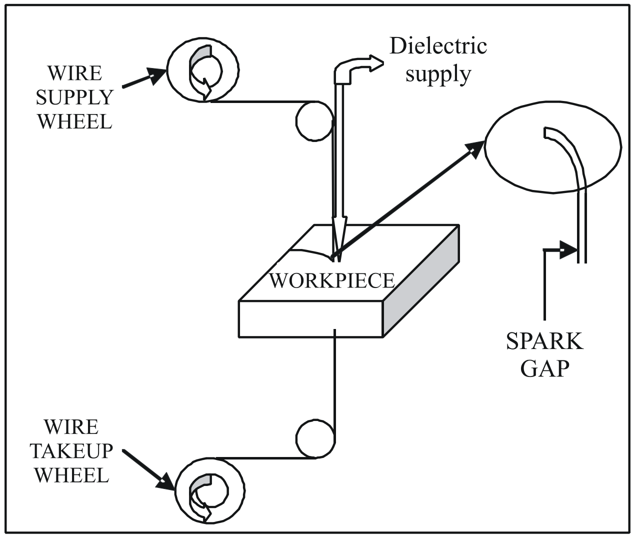

Fig. 1 *" Wire electric discharge machining (WEDM) model*

3. DEVELOPMENTS IN WIRE ELECTRODES

I. Development Targets

The high-speed and high-precision machining can be realized through improvement of the electrical discharge machining performance since; the important process variables have direct effect on performance characteristics such as machinability, machining speed etc. For high speed cutting and high precision machining any wire electrode should have key physical properties viz; high conductivity, tensile strength, elongation, straightness etc. In wire EDM, strength has only a minimal impact on wire breakage while toughness controls its frequency. However, the material characteristic such as fracture toughness has been shown to control wire breakage frequency [3]. An EDM wire will break when a discharge (or DC arc) introduces a flaw in the wire which is greater than the critical flaw size necessary to produce catastrophic failure under the preload tension that has been applied. Many high strength materials, including EDM wires, are notorious for their low fracture toughness, that is, their inability to withstand relatively small flaws without failing. Each and every discharge in the EDM process makes a crater, which is termed as defect or flaw, in both the wire and the workpiece [4]. As flushing conditions deteriorate, those flaws tend to become larger and larger, eventually causing catastrophic failure of the wire.

II. Zinc Coatings Promote Speed and Performance

More zinc in wire electrode would enhance the performance of WEDM but it is problematic to increase the percentage of zinc in the wire to more than 40 percent, due to wire drawing problems. Changes in the wire grain structure make the wire too brittle for further processing into the fine diameters necessary for wire EDM [5].To circumvent this, the zinc is added to the surface of the wire. Zinc-coated wire can go through a secondary heat treatment process in an oxygen atmosphere. This produces a very thin layer of oxide on the zinc surface which in turn helps the wire slide through the wire guide and protects the softer zinc from flaking. These coated wires offer highest level of productivity with faster cutting speed.

III. Development of Brass wires

Various attempts have been made in the past to improve wire electrodes. Copper, which was in common use at first, has been replaced by brass. It has been discovered that the addition of zinc (zinc + copper = brass) improves the cutting performance and speed when compared to the copper in several ways. During the cutting process, the zinc in the brass wire actually boils off, or vaporizes, which helps cool the wire and delivers more usable energy to the work zone [6]. In some circumstances significant brass deposit can remain on the workpiece after the cut which is proved to be difficult to remove. Since, it is not practical to cold draw wire with higher zinc content in excess of 40%, which led to the development of coated wires [7]. Fig. 2 shows the cross-section of plain brass wire electrode having composition Cu 65% Zn 35%.

Fig. 2 Cross-section of plain brass wire electrode

IV. Coated wire electrodes [Copper/Brass Core]

One of the earliest patents on Zinc coated wires [US Patent 1896613-1933] directed towards improvement in the quality of Zinc coated wires as shown in Fig.3. In US Patent No. 14,927-1979, it was disclosed that wire electrode coated with a metal or alloy having a low vaporization temperature, such as zinc, cadmium, tin, lead, antimony, bismuth and alloys thereof, protecting the core of the wire against thermal shock resulting from the occurrence of electrical discharges and which permits to increase the frequency of the electrical discharges without running the risk of rupturing the wire. US Patent No. 4,968,867-90 discloses a wire electrode for wire cut electrical discharge machining, which includes a core wire having relatively high thermal conductivity, a lower coating layer formed by a low-boiling point material (for example, zinc) and an outermost layer of brass having high mechanical strength. An EDM wire with a copper bearing core and a substantially continuous coating of porous epsilon phase brass, wherein said porous coating has been infiltrated with graphite particles [US Patent No. 20070295695].

Fig.3 Cross-section of coated wire electrode

V. Coated wire electrodes [steel Core]

To achieve high strength and rigidity, coating is plated on steel wires. For best machining performance EDM electrodes must have a good electrical conductance, which enables high machining current to flow through the electrode and it must have high mechanical strength for increased traction force through machining zone. In order to obtain both the benefits wire electrode with first coating of copper on steel wire and then plating a coating of zinc, cadmium, tin, lead, antimony, bismuth or alloys thereof was developed [US Patent 4287404-1981]. Korean Patent No. 10-1985-0009194 discloses a wire electrode for an electrical discharge machining, which includes a steel core coated with copper or other components, and copper-zinc alloy layer of CuZn10˜CuZn50 coated on the steel core. It is also known from the prior art, for instance from U.S. Patent No. 4,686,153-87, to coat a copper clad steel wire with zinc and thereafter to heat the zinc coated wire to cause inter-diffusion between the copper and zinc to thereby convert the zinc layer into a copper zinc alloy. U.S. Patent No. 5,762,726-98 recognized that the higher zinc content phases in the copper-zinc system, specifically gamma phase, would be more desirable for EDM wire electrodes, but the inability to cope with the brittleness of these phases limited the commercial feasibility of manufacturing such wire. U.S. Patent No. 4,998,552-91 discloses a wire electrode for a traveling wire EDM method, which includes a core made of steel, a lower layer made of homogeneous copper (Cu of 100%) and an upper brass layer including zinc of 50% by weight. The core made of steel is surrounded by copper or copper alloy to form a multi-layer structure, thereby having a relatively large mechanical strength [Fig. 4]. It has been observed due to the electric discharge, a force opposite to the machining direction is created on the machining sections of the wire electrode. Also electrostatic and electromagnetic forces are created on the wire electrode. Due to all these forces and due to the vibrations of the wire, the actual position of the wire is different from the programmed position. This results in accuracy and precision problems. Deviation from the programmed outline at the corners has as result that round corners are obtained instead of the desired sharp corners. This led to the development of plain Mo (Molybdenum) or W (tungsten)- wires due to their high tensile strength (>1900 MPa). Owing to the drawback of being expensive and poor flushability new type of wire comprising a high strength perlite steel wire having carbon content higher than 0.06% and wire being coating of copper free Zinc or Zinc alloy coating was Developed. This results in improved precision and accuracy with increased mechanical load. Higher machining speed and improved surface finish was also obtained [US patent No.6875943-2005].

Fig. 4 Cross-section of steel core coated wire

VI. Diffusion annealed wires

Since Zinc coating has proved to be the ultimate coating for better performance. Zinc has low meting point and requirement of wires of high zinc content coating and high melting point led to the development of diffusion annealed wires. It was disclosed in US patent No.4935594-90 that the outer layers of coated wire has rich zinc alloy. The encased wire is then annealed at such temperature until alloy extends from outer surface to the core. The wire so produced has a structural composition in its outer coating having much greater resistance with respect to erosive wear than common eroding electrode. Another attempt was made to improve the mechanical strength of electrodes while maintain their benefits such as heat shield effect, elimination of shot circuits. Production rates are also increased with this invention [US Patent No. 5196665-90]. In many wire EDM applications, the surface finish of the part being fabricated is of critical importance, it is therefore desired to improve the speed of cutting without degrading the surface finish achieved by the cutting process. It was disclosed in U.S. Patent No.5, 945,010-97, that coating is comprised of a copper-zinc alloy or the coating is comprised of a nickel-zinc alloy. The core may be comprised of copper clad steel, brass, or other suitable material. The coating second metal may consist of a metal selected from the group consisting of zinc, magnesium and aluminum by employing low temperature diffusion anneals. The resulting EDM wire cuts faster and better surface finish than conventional EDM wire electrodes, or is capable of producing a superior finish at competitive metal removal rates. A further advantage of the invention is that the higher zinc content in the coating compared to earlier invention EDM wire will result in a significantly lower volumetric heat of sublimation for the coating and therefore cause the wire to flush more efficiently while having enough tenacity to survive the EDM erosion process.

However in certain cases diffusion annealed wires are not advantageous due to non uniform zinc composition and non uniform alloy composition. This led to the development of hot dip galvanization method. This method is advantageous in terms of formation of uniformly coated zinc on the wires. [US patent No. 20060138091].

4. Conclusions

Plain brass was an advance over copper wires. Composite wires have replaced zinc-coated as the wire of choice for workpieces. The Composite wires have a plain carbon steel core that is surrounded by a layer of pure copper and coated on the outside with zinc-enriched brass. Wires with greater tensile strength can be made, but they face diminishing benefits in terms of increased resistance to breakage, and greater tensile strength is usually obtained at the expense of fracture toughness.. The zinc-enriched outer coating of brass improves flushability, its thickness determines how long it will last in the cut. Diffusion annealed wires offer resistance to breakage. Alpha phase, beta phase and gamma phase coatings have significant improvement over plain wires. These high performance wires significantly increase wire EDM productivity but are associated with certain limitations such as high cost, flaking, straightness and possible damage to scrap chopper and may not be used on all the wire EDM machines.

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