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ORIGINAL ARTICLE

Review of improvements in wire electrode properties for longer working time and utilization in wire EDM machining

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Abstract Wire electrical discharge machining (WEDM) is an important technology, which demands high-speed cutting and high-precision machining to realize productivity and improved accuracy for manufacturing hard materials. WEDM has experienced explosive growth and complexity of equipment as well as rising demand for the basic process tool (the wire electrode). Greater taper angles, thicker workpieces, automatic wire threading, and long periods of unattended operation make the selection of the ideal wire a much more critical basis for achieving successful operation. This paper focuses on the evolution of EDM wire electrode technologies from using copper to the widely employed brass wire electrodes and from brass wire electrodes to the latest coated wire electrodes. Wire electrodes have been developed to help user demand and needs through maximum productivity and quantity by choosing the best wire. In the final part of the paper, the possible trends for future WEDM electrode research are discussed.

Keywords WEDM · Coated wires · Brass wires · Steel wires · Diffusion annealed · Composite wire electrodes

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1 Introduction

Wire electrical discharge machining (WEDM) is among the more widely known and applied non-traditional machining processes in industry today. In this procedure, improvements to the process mechanism and control have rapidly been taking place. WEDM can machine harder, they are higher strength, corrosive and wear-resistant, and difficult-to-machine materials. With WEDM, it is also possible to machine complicated shapes that cannot otherwise be achieved using traditional machining processes, such as turning, milling, and grinding. Applications of WEDM include extrusion dies, fuel injector nozzles, aircraft engine turbine blades, and machining of difficult-to-machine materials like tool steel, titanium, metal matrix composites (MMCs), and cemented carbides [1–5]. Besides machining electrically conductive workpieces, some WEDM work has also been reported on insulating ceramics and non-conductive materials [6–9].

The Russian Lazarenko couple designed the first electrodischarge machine in 1955 [10]. Ten years later, a numerically controllable wire discharge machine was developed, and in 1969, a machine for mass production was built. Most wire discharge machine controllers have been enhanced with computer numerical control equipment. As for wire electrodes, pure copper wires were used in the early 1970s but at the cost of accuracy and strength. In the second half of the 1970s, brass wire started to be used instead of pure copper wire. In 1980, copper wire electrodes coated with zinc and, in the following year, brass wire electrodes coated with zinc were developed and utilized. Brass wire electrodes with added aluminum or chromium were made as well. From 1990 onwards, brass wire electrodes coated with zinc for high-precision cutting and coated Cu-50mass%Zn for high-speed cutting were developed. Subsequently, core materials of stainless wire coated with copper were made and utilized. Also, new types of wire were developed which offered higher

cutting speed due to increased zinc concentration and wire electrodes made of brass with added titanium and aluminum for improved heat resistance when cutting thick materials [11, 12]. Moreover, other special wire electrodes were developed to meet specific cutting conditions and materials, such as steel, tungsten, molybdenum, and abrasive-assisted and porous wire electrodes [13].

As for WEDM, demand is on the rise for high-speed cutting and high-precision machining for the purpose of improving the productivity of molds as well as for achieving high-quality machined workpieces. Wires used in WEDM are the core of the system. Brass wire electrodes are extensively used as WEDM tools. However, along with recent variations in manufacturing field applications, there is an expanding demand for wire electrodes with superior performance to the conventional brass wire electrodes. High-performance wires, including coated, composite, and diffusion-annealed wires are characterized by high conductivity and good sparking ability. These electrodes are generally zinc-coated wires with a copper-brass alloy or steel core, the brass containing either a small amount of chromium or high concentration of zinc. At present, WEDM users are interested in shortening the machining time of products [14–17]. A new, high-performance EDM wire would be expected to provide both high cutting speed and improved accuracy. Thus, this paper focuses on studying improvements of physical, mechanical, and electrical properties of wire electrodes for high-performance WEDM processes.

2 Wire EDM process

In WEDM, material removal is based upon the electrodischarge erosion effect of electric sparks occurring between the wire electrode and workpiece. The two are separated by a dielectric fluid, as shown in Fig. 1. A pulse voltage is applied between the wire electrode and workpiece in the processing fluid to melt the workpiece surface with the thermal energy of a spark discharge, while simultaneously removing machining dust through a vaporizing explosion and recirculation of the processing fluid. Continuous machining thus becomes possible while running the wire electrode. The residue ensuing from the melting and vaporization of a small volume of the surfaces of both workpiece and EDM wire electrode is contained in a gaseous envelope (plasma). The plasma eventually collapses during off-time. The liquid and vapor phases created by the melting and vaporization of the material are quenched by the dielectric fluid to form solid debris. This process is repeated at nanosecond intervals (depending on the cycle time) along the length of the wire in the cutting zone [18–20].

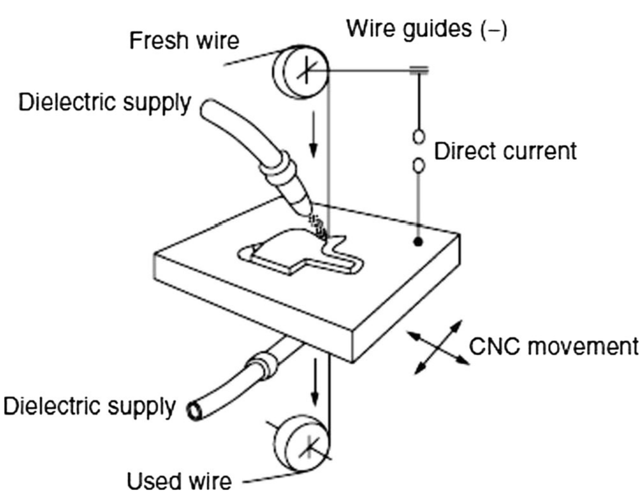

Fig. 1 Wire electric discharge machining (WEDM) schematic diagram

To achieve a successful operation, selecting the correct wire electrode for WEDM is a very challenging task [21]. As a result, experimentation with different wire electrodes is essential if optimum results are to be achieved. The wire electrodes used in WEDM must have two important characteristics: high electrical conductivity and sufficient mechanical strength. WEDM performance is attributed to mainly six factors, as shown in Fig. 2 [22–24].

3 Wire electrode properties

In general, the cutting performance of the WEDM procedure depends on a combination of electrical, mechanical, physical, and geometrical properties of the wire electrode. The factors not related to the wire but which are involved in WEDM, including the mechanical machine concept, improved machine intelligence, use of new pulse generators, and dielectric flushing techniques, also affect machining performance. The following section describes the key physical properties of EDM wires and how they relate to real-world cutting [25–27].

Conductivity is an important property of the EDM wire since it determines how the power supply energy is transferred over the distance from the power feed source to the actual point of cutting. This distance can be considerable, especially if the job is to cut with open guides to clear a workpiece obstruction. Low wire conductivity will result in a voltage drop and associated energy loss over the distance from the power feed to the cutting point. This is not insignificant considering that the peak current of most modern power supplies often exceeds 100 amps. Conductivity is often expressed as a percentage of IACS (International Annealed Copper Standard), which is a unit of electrical conductivity for metals and alloys relative to standard annealed copper [28].

Tensile strength indicates the wire's ability to withstand the tension imposed upon it during cutting in order to