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Analysis of surface morphology and topography of pure aluminium machined using WEDM

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A B S T R A C T

Wire electrical discharge machining (WEDM) represents the effective technology of unconventional machining used for the manufacture of components with complex shapes, for machining of hard materials following heat treatment or of non-ferrous metals that are difficult to machine with conventional processes. One non-ferrous material is pure aluminium 99.5 which is used for this experiment: for the design of the experiment, machine parameters were setup for the fabrication of 33 samples aluminium 99.5. The objective of this study was to find the key parameters of machine setup for the manufacture of high-precision components with the required surface quality. For this purpose, an analysis of the morphology of the surface layer was made using electron microscopy (SEM), including a local analysis of the chemical composition (EDX). In addition, the surface topography using 3D profilometer and profile and area parameters of the surface quality were evaluated, including 3D colour filtered and unfiltered images of surfaces taken using light microscopy. The prepared metallographic preparations allowed an analysis of the sub-surface area, including a local chemical microanalysis of "recast layer" using EDX. This study discovered the optimal setting of machining parameters (gap voltage = 70 V, pulse on time = 6 µs, pulse off time = 50 µs, discharge current = 25 A and wire feed = 14 m·min^{-1}) for the best quality of machined surface and the narrowest width of kerf for precision machining.

1. Introduction

The unconventional technology of wire electrical discharge machining (WEDM) employs only physical principles for material cutting instead of classical mechanical power. Machined material is immersed in a dielectric liquid, and brass wire with a diameter of 0.3–0.02 mm is usually used as a tool electrode [1,2]. Material is removed in the form of microscopic particles due to periodically recurring electrical discharges between the workpiece and thewire. Electrically discharged material particles are subsequently carried away from the cut area by a flushing jet of dielectric liquid that also provides cooling of the component being machined [3–5].

Using WEDM, it is possible to machine all materials featuring at least minimum conductivity, and no requirements are imposed for minimum or maximum hardness of the machined material. Since no mechanical forces affect the material during the process, it is also possible to machine thin-walled components made from low hardness materials without the risk of getting the walls of products warped and their geometry changed. Besides, the technology is also suited to the machining of components with very complex shapes, including micro-machining where the diameter of the wire electrode represents the major limiting factor [6,7].

Prasad [8] focused on the effect of different wire electrical discharge machining (WEDM) process parameters on the damping behaviour of the aluminium alloy. The parameters such as pulse on time, pulse off time and peak current were employed, which they consider to be most significant. The results of the experiment revealed that the damping behaviour greatly depends on the wire EDM process parameters. Rao [9] investigated the optimization of wire EDM and claims that the quality of a wire EDM surface is strongly influenced by its parameter settings and the material to be machined. Both Prasad and Rao mainly focused on the usage of heavy metals and partly on titanium and magnesium alloys in light metals, although an attempt has been made to study the effect of wire EDM parameters on aluminium alloy because of its growing application in various industries. Reddy [10] performed an experiment to study the multiple response optimization of wire EDM on aluminium. Reddy claims that complicated cuts can be made through difficult-to-machine electrically conductive components.

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Bobbili [11] investigated a multi response optimization technique for wireEDM operations on ballistic grade aluminium alloy for armour applications. Four machining variables were used for the experiment: pulse-on time, pulse-off time, peak current and spark voltage, which proved to be significant to the Grey relational grade. Cheng [12] employed the high-speed wire electrical discharge machining (WEDM-HS) for processing of the pure aluminium (Al) oxide film to research its performance influenced by the WEDM technology. This method proved to greatly improve the outputs of the research by reducing the abrasive wear and adhesive wear, and increasing the anti-erosion ability.

There are many factors that have an essential effect on the resulting quality of the machined surface. These, in particular, include machine setup parameters and a set of mechanical and physical properties of the material to be machined, including the type of its additional heat treatment. Understanding in detail the input factors of the process of machining of individual materials and their heat treatments is a very extensive task. Nevertheless, it is necessary to find the optimum machine setup parameters for individual materials and their heat treatmentsto ensure effective machining with required accuracy and surface quality. Another objective of this study was the investigation of possible surface and undersurface defects, where cracks could occur due to inappropriately selected machining parameters. The occurrence of cracks significantly affects the life and accuracy of the machined parts. The research builds on the works already published by the author, which were aimed at the optimization and subsequent evaluation of machined surfaces using the WEDM technology [13–21].

2. Experimental setup and material

2.1. Experimental material

The samples for the experiment were made of pure aluminium Al 99.5 with chemical composition according to Fig. 1. Aluminium Al 99.5 is a material with low specific weight. Its undeniable advantages include: excellent corrosion resistance, good weldability, and suitability for anodizing. Depending on the type of semi-finished products and grain size, the hardness of this material ranges from 20 to 42 HBW and its tensile strength is between 65 and 160 MPa (depending on the loadingdirection relative to the axis of the semi-finished product). It is used in nearly all industries for structural members and joints subjected to low mechanical stress, requiring a material with high ductility, considerable corrosion resistance and good thermal and electrical conductivity. It is practically weldable in any manner. For our experiment we used bar stock with a diameter of 20 mm as an initial semi-finished product from which a prism was fabricated using wire electrical discharge machining.

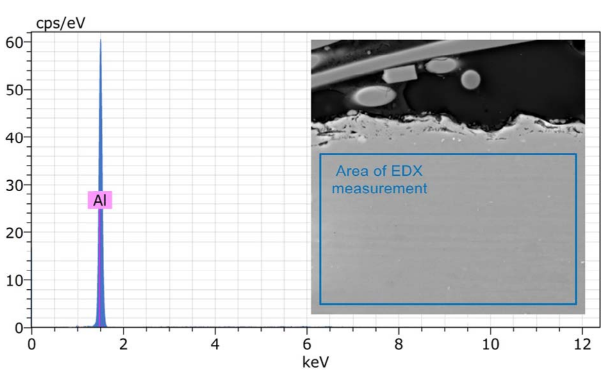

Fig. 1. Place of measurement of analysis of chemical composition EDX for machined material pure aluminium.

Table 1
Limits of machine setup parameters.

Parameter	Gap voltage (V)	Pulse on time (μs)	Pulse off time (μs)	Wire speed ($m \cdot min^{-1}$)	Discharge current (A)
Level 1	50	6	50	10	25
Level 2	60	8	40	12	30
Level 3	70	10	30	14	35

2.2. WEDM machine setup

The WEDM machine used in this study was the high precision five axis CNC machine MAKINO EU64. For the electrode, brass wire (60 % Cu and 40 % Zn) PENTA CUT E with a diameter of 0.25 mm was used. Samples were immersed in the deionized water which served as dielectric media and also removed debris in the gap between the wire electrode and workpiece during the process.

The designed experiment was based on the monitoring of effects of five independent technological parameters of the cutting process, i.e. gap voltage(U), pulse on time (T_{on}), pulse off time (T_{off}), discharge current (I), wire feed (v), and their limit values (Table 1). The limit values of individual parameters setup were determined based on previously made extensive testing [22].

For the experiment, the “half response surface design” containing 33 runs arranged in two blocks (Table 2) was selected. In order to reduce the possibility of systematic errors, the individual runs are randomized; to achieve a better noise factor, 7 middle points were added to the experiment. A detailed description of this data collectiondesigncan be found, for example, in Montgomery [23].

During the machining process, the actual cutting speed of the machine was read out and the number of wire electrode breakings on each sample was recorded; i.e. along a cut length of 3 mm, as can be seen on the machined sample – refer to Fig. 2. Cutting speed for all samples ranged from 10 to 12 $mm \cdot min^{-1}$, and only 6 samples were not machined at a cutting speed of 12 $mm \cdot min^{-1}$. The number of wire electrode breakings was very small; the latter occurred only in 5 samples with a maximum of 3 breakings. Wire electrode breaking is caused by inappropriately set machining parameters and is described in detail in various other studies [24,25].

3. Analysis of the machined surface

3.1. Experimental methods

Machined surfaces of the samples were cleaned in an ultrasonic cleaner and studied using the scanning electron microscope (SEM) LYRA3 by Tescan. This microscope was equipped with energy-dispersive X-ray spectroscopy (EDX), which enabled thestudy of the changes in the chemical composition of the surface of the cut material as a result of WEDM machining. Area and profile parameters of the machined surface were studied using the 3D contactless profilometer IFM G4by Aliconabased on the principle of coherence correlation interferometry. The measured data were analysed by means ofIF-Laboratory Measurement software delivered by Alicona. In order to analyze the surface and sub-surface microstructural changes as well as changes in chemical composition of the material machined using WEDM method, metallographic cross sections were prepared. These preparations were made using common techniques; i.e. by wet grinding and polishing with diamond pastes using the TEGRAMIN 30 automatic preparation system byStruers. Final mechanico-chemical polishing was made with OP-Chemsuspension byStruers. Having been etched with Keler’s Reagent, the material structure was examined and documented using the LYRA3 electron microscope. The surface morphology and total height of profile were studied by means of the OLYMPUS DSX 510