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Original Research Article

Experimental study on surface characteristics and improvement of microelectrode machined by low speed wire electrical discharge turning

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ABSTRACT

Electrical discharge machining (EDM) as the nontraditional machining process has a unique superiority in fabricating microelectrodes due to its non-contact removal mechanism. Therefore, the method of LS-WEDT (low speed wire electrical discharge turning) is firstly proposed to fabricate microelectrodes in this study. More importantly, the multiple cutting strategy is introduced to divide the machining process into rough cut (RC), trim cut (TC) and finishing trim cut (FTC). Experimental results showed that the ridges will appear after RC, the spherical droplets congregation phenomenon can be observed after TC and the surface will be covered with refined grains in nano level after FTC, which disclosed the unique surface characteristics of LS-WEDT. After FTC, the microelectrode of 90 μm in diameter and 1000 μm in length is successfully and firstly fabricated by LS-WEDT method, moreover, it has good surface quality with Ra of 0.59 μm and high dimensional precision with surface profile accuracy of 3.22 μm. Additionally, the comparative analysis was made to investigate the LS-WEDTed and LS-WEDMed surface, the discharge craters distributed in LS-WEDTed surface are longer than LS-WEDM. Finally, the surface quality machined by LS-WEDT after FTC is better than LS-WEDM, which is attributed to the point contact and good flushing conditions.

1. Introduction

Nowadays, the micro-electro mechanical system (MEMS) has come to a practical period and micromachining technique plays an irreplaceable role in miniaturization of components and parts [1,2]. As the tools of micromachining, the demand of microelectrodes has greatly increased. EDM as the nontraditional machining process has a unique superiority in fabricating microelectrode due to its non-contact, no macro cutting force and not restricted by the material properties [3–5]. More importantly, the discharge mechanism makes it can obtain the prospective removal unit and even realizes the sub-micron material removal in theory. Therefore, the EDM technology has the broad application space in manufacturing complex micro parts, micro cutting tools, microelectrodes and micro mold [6].

Many researchers make their efforts to fabricate microelectrodes using EDM method. Yamazaki et al. [7] adopted self-drilled holes to form microelectrodes, but it still had taper errors in the axis direction even after copying seven times. Mohria et al. [8] used micro-scanning electrical discharge

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machining method to manufacture microelectrodes, which has high efficiency but the control system is complicated. Lim et al. [9] adopted EDM process to fabricate microelectrodes with high-aspect ratio using a sacrificial electrode. Kim et al. [10] fabricated microelectrodes of various shapes by reverse electrical discharge machining (REDM) and obtained the optimal conditions for stable machining. Haddad et al. [11] used cylindrical wire electrical discharge turning (CWEDT) to fabricate revolving parts and investigated the effect of machining parameters on material removal rate (MRR), surface roughness and roundness using analysis of variance (ANOVA), moreover, the MRR model is developed using response surface methodology (RSM). Gjeldum et al. [12] built the mathematical model for MRR of CWEDT by neural network programming and disclosed that the rotating speed has a small influence on MRR. Krishnan et al. [13] optimized the CWEDT processing parameters using non-dominated sorting genetic algorithm-II (NSGA-II) and then predicted the Ra and MRR by adopting artificial neural network (ANN). Mohammadi et al. [14] obtained the optimum parameter combination of CWEDT for the minimum Ra and roundness using the analysis of S/N ratios, and they also found that only power has a significant effect on the Ra. Janardhan et al. [15] used the pulse train data acquired at the spark gap to analyze the effect of processing parameters in MRR, Ra and roundness error of wire electro discharge turning. Since EDM is a thermal process, the workpiece surface will be subjected to the instantaneous high temperature (10,000 °C) and cooling, which significantly affects surface topography, chemical composition, metallographic structure and surface physical properties [16–19]. Therefore, many researchers also focused on studying the surface and sub-surface quality of workpiece machined by EDM or WEDM. Ekmekci [20] investigated surface integrity of mold steel machined by EDM and they found that the high tensile residual stress makes the white layer appear some microcracks. Lee et al. [21] studied the relationship between EDM parameters and surface cracks by a full factorial design, and then they established a crack prediction map. Bleys et al. [22] investigated surface and sub-surface quality of tool steel machined by EDM.

The available literature mainly involves in improving the surface quality by investigating the multi-objective optimization using NSGA-II, developing Ra mathematical models using RSM and predicting Ra using ANN, but the most effective and feasible method to improve surface quality and machining accuracy is multiple cutting strategy. Besides, as for microelectrode fabrication, many EDM methods have been proposed but all these methods have their unique characteristic and applied range, which cannot meet the requirements of high dimensional precision, high machining efficiency, good surface quality, low cost and complicated micro structure at the same time. Therefore, this paper firstly makes our attempts to use LS-WEDM machine to fabricate microelectrodes. At last, in terms of surface quality, although some researchers focused on investigating surface integrity of workpiece machined by WEDM or EDM including microstructure, microcracks, microvoids, the white layer and chemical composition, it is not suitable for LS-WEDT due to the workpiece's rotating movement and the point contact discharge area will have a significant influence on the mechanism of discharge channel, material removal and crater formation, which makes LS-WEDT different from EDM and WEDM. The method of LS-WEDT is firstly proposed to fabricate microelectrodes in this paper. And the multiple cutting strategy is introduced to the microelectrode fabrication for improving the surface integrity. Besides, the surface quality of microelectrodes including Ra, surface morphology, microvoids, cracks, grained refinement, surface metal migration, surface profile accuracy, surface height frequency and surface spherical droplets congregation obtained by LS-WEDT in RC, TC and FTC are respectively discussed. Finally, the contrast experiments of LS-WEDM are conducted to disclose the different discharge mechanism of LS-WEDT.

2. Experimental procedure

2.1. LS-WEDT method

The schematic diagram of LS-WEDM is illustrated in Fig. 1(a), and material is eroded by a series of discrete sparks occurring in the gap between workpiece and wire electrode. Then the debris is flushed away from the gap by the continuously supplied working fluid. Inspired by WEDG, the LS-WEDT concept is firstly put forward to manufacture microelectrodes and its configuration is displayed in Fig. 1(b), the wire electrode does one-way movement at a constant speed V_w in the vertical direction. The microelectrode does rotary motion at a rotating

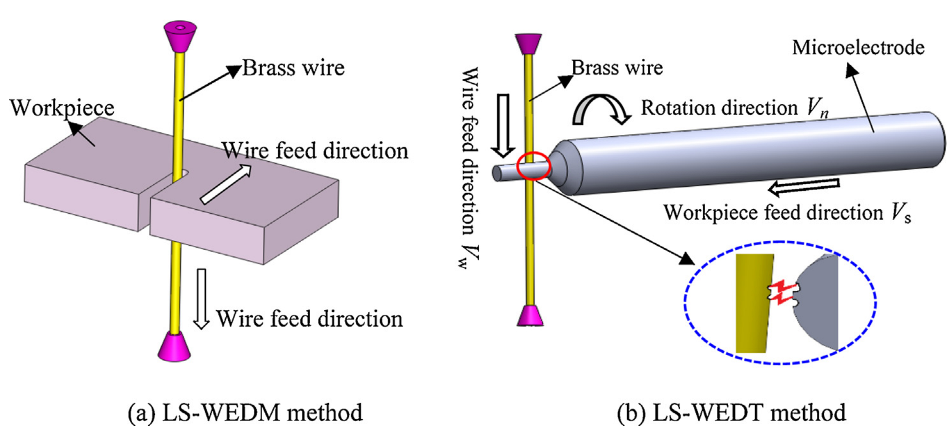

Fig. 1 – The schematic diagram of LS-WEDM and LS-WEDT method.