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Geometric simulation of electro-erosion edge honing: Insights into process mechanisms

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ABSTRACT

A serious limitation of sink electrical discharge machining is the rapid geometric degeneration of sharp features due to localized wear. Electro-erosion edge honing is a novel process that creatively exploits this phenomenon for the edge preparation of cutting tools. This paper presents a geometric model of the process that can accurately predict the profiles of both symmetric and asymmetric edges that are prepared in the process. Numerical simulation of the model quantifies the concept of relative duty in the context of the process, and offers unique insights into process mechanisms. In particular, the critical influence of the wear ratio in determining the prepared edge being either rounded or chamfered is clarified, in consideration of the trajectory of successive discharge trains. The work further enables an understanding of the influence of initial edge defects on the processed edge, and presents guidelines for optimizing edge quality.

1. Introduction

Electro-erosion edge honing (EEEH) is a novel tool edge preparation process [1]. The process capitalizes on the inherent limitation of sink electrical discharge machining (EDM) that sharp edges on tool electrodes rapidly degenerate into a rounded shape. The principle in this process is to sink the nominally sharp edge of a ground or an as-pressed insert into an appropriate counterface material (Fig. 1a), so as to generate a rounded edge by selective thermal erosion of the material from the tool edge. Tool inserts with a complex edge profile can be prepared by using foil counterfaces (Fig. 1b), with the foil thickness determining the extent of edge rounding [2]. The process can be configured to simultaneously prepare a batch of inserts, to generate both symmetric and asymmetric edge hones, and to bring about a defined variation in the edge radius along the cutting edge.

Tool inserts may be honed in this innovative process irrespective of their hardness, as long as their electrical conductivity is sufficient for EDM. This renders it applicable to such tooling as metal-bonded polycrystalline diamond compacts that are difficult to process by mechanical means, on account of their extreme hardness. Furthermore, as the volume of material that is to be removed from the cutting edge to generate the edge hone is indeed minuscule, the relatively low material removal rate of EDM is of no detriment in this process. This aspect as well allows for the application of conservative pulse energy levels, which limits possible thermal damage to the cutting edge that can adversely influence tool life. In reference to the excellent machining precision that is characteristic of EDM, the process also corresponds to minimal variability in edge geometry [2], as compared to conventional brush honing and micro-blasting processes. This is of much industrial significance in terms of robust tool performance, which has beneficial implications when cutting high-value components.

Considering that direct experimental observation of gap phenomena in the EEEH process is difficult if not impossible, the work reported in this paper focused on applying geometric simulation to understand the process in fundamental terms. Geometric simulation of sink EDM seems to have been first reported by Tricarico et al. [3] in the late eighties to investigate the evolution of workpiece boundary in consideration of tool wear and gap width. Kunieda et al. [4] advanced this technique by modelling the tool and workpiece as mesh elements. This facilitated the integration of individual craters as basic units of material removal, with reference to discharge locations determined by the local gap width and machining debris. The model was subsequently enhanced to be applicable to profiles with fine geometric features, by incorporating the concept of relative duty, which refers to the effect of profile curvature on the local removal rate [5].

As opposed to cubic mesh elements considered in the aforementioned works, conic crater shapes have also been considered [6]. In their work on micro-EDM of blind holes, Jeong and Min [7]

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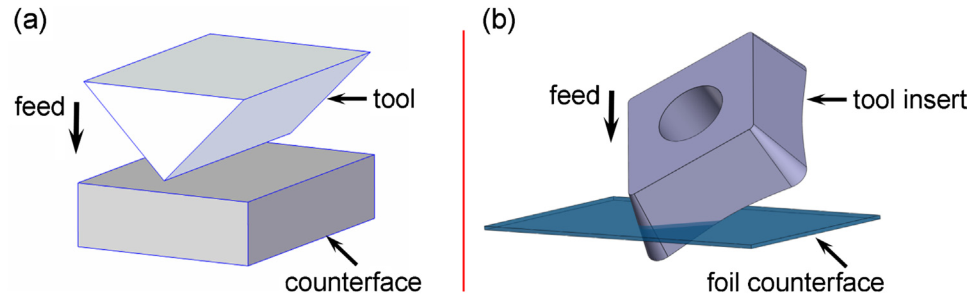

Fig. 1. Principle of electro-erosion edge honing process [1,2]. The difference in terminology between this process and conventional EDM, which is a consequence of a tool being machined in this novel process, is to be noted: the electrodes in this process shown above are referred to as the tool (that is normally the workpiece in EDM) and the counterface (which commonly is the tool in EDM).

considered the role of local surface topography on the removal volume per spark, and were successful in employing geometric simulation for off-line tool wear compensation. Izquierdo et al. [8] considered the temperature fields in the workpiece due to superposition of multiple discharges, and on appropriate calibration of relevant parameters, were able to predict the removal rate and surface finish to within several percent of that observed experimentally. Further details on geometric simulation of EDM as well as its applications can be found in a review paper by Hinduja and Kunieda [9].

The particular objectives of this research were two-fold: (i) to gain insights into the mechanism of shape generation in the EEEH process, and (ii) to formulate a model for the quantitative prediction of the final edge geometry with reference to process/edge geometric conditions. To this end, geometric simulation was used as a tool to comprehend shape evolution of the edge with the progression of material removal, by continuously tracking the envelope of overlapping micro-craters that collectively constitute the generated edge profile. Previous experimental work [1,2] indicated the ratio of the volume of material removed from the tool electrode to that from the counterface (defined as the wear ratio ν in the context of this new process) to play a decisive role in the micro-geometry of the prepared edge being either chamfered or rounded. It was hence of interest to apply the model to investigate the influence of the wear ratio, and to clarify the mechanism behind such an intriguing transition that is of practical relevance. In addition to understanding this phenomenon, the application of the model in comprehending the variability in the micro-geometry of the prepared edges was also investigated.

2. Simulation

2.1. Methodology

Simulation of the EEEH process was undertaken in a two-dimensional plane, with the cutting edge and counterface modelled as two arrays of equispaced nodes. The simulation technique referred to geometric (tool wedge angle, initial edge radius, foil thickness) and process (gap width, crater geometry) parameters. The material removed per discharge was assumed to be constant, with information on the crater geometry and gap width required for the simulation obtained experimentally.

The location of discharges in EDM is non-deterministic, and is dependent on the local dielectric strength determined by the level of gap contamination, and the imposed field intensity [10]. Given that typical edge radius values are on the order of only a few tens of μm and that the process refers to conservative pulse parameters, the volume rate of debris generation in EEEH is negligibly small as compared to conventional EDM processes. This combined with the fairly open process geometry facilitates rapid and even dispersal of the gas bubbles and the machining debris. Discharges were hence assumed to occur across a gap (that is nominally of an even width) at locations that correspond to the shortest distance between the tool and the counterface, with no consideration for the debris field.

The feed motion in the process was simulated by moving the tool towards the counterface such that the gap width was maintained within limits that correspond to the nominal value measured experimentally. Material removal was thereafter simulated at nodes on the tool and counterface that correspond to the minimum distance between the tool and the counterface (called the sparking nodes). This cycle was repeated to the completion of the process. Crater profiles were assumed to be a segment of a circle, with width w and depth d (Fig. 2a) such that the radius of curvature R is given by $[(w^2 + 4d^2)/8d]$. The corresponding crater area A_c in the plane of the 2D simulation can be calculated as:

$$A_c = R^2 \cos^{-1}\left(\frac{R-d}{R}\right) - (R-d)\sqrt{2Rd - d^2} \quad (1)$$

A_c was measured experimentally for the tool and counterface, as detailed later in Section 2.2. Craters were also considered to be oriented perpendicular to the spark with the sparking nodes located on the axes of symmetry. The spark orientation was defined by the angle θ with respect to the horizontal (Fig. 2a). In order to adequately capture the crater geometry in the simulation, the node spacing was such that a single crater spanned several nodes, Fig. 2b. With the profile of the crater section readily computed, the coordinates of the tool and the counterface were updated after every discharge, as illustrated in Fig. 2b.

On iterating this step to simulate overlapping craters from successive discharges, the effect of the curvature and topography of the generated profile has to be adequately considered. For instance, referring to Fig. 2c, the material removed in the second discharge is smaller than in the first one, and is also smaller than the reference crater area A_c calculated using Eq. (1) due to the local topography of the profiles. The width and depth of the craters were hence proportionally incremented such that the material removed in each discharge corresponds to A_c, for both the tool and the counterface. This will in turn secure the correspondence between the simulated and measured wear ratio. For the first few sparks, the profiles of overlapping craters simulated with this methodology is shown in Fig. 2d.

2.2. Experimental details and model calibration

Geometric simulation of the EEEH process necessitates empirical information on such parameters as the wear ratio, gap width and crater geometry, which depend on the pulse parameters, polarity and the electrode/counterface materials. EEEH experiments involved an oil-based dielectric fluid, an aluminum counterface of negative polarity, a pulse on-time of 0.4 μs, a pulse off-time of 1.12 μs, an average gap voltage of 50 V, and a pulse current of

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