Fabrication of smooth surfaces in hardened tool steel using µ-EDM technology

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Abstract

In this paper a process optimization was conducted to enable the achievement of smoothest surfaces in hardened tool steel using µ-EDM technology. The trials were carried out using DoE-Methods, aiming therefore the limitation on the number of experiments. The paper gives detailed information on the experimental procedure applied and on the achieved results, considering surface roughness and sub-surface damage as well as crack formation on the work piece surface.

1 Introduction

Electrical-discharge machining (EDM) is a manufacturing technology which is applied mainly for the fabrication of dies and moulds, for the manufacture of micro boreholes for fuel injectors and cooling holes in turbine blades, as well as for machining of seal slots in turbine components. All these components are made of difficult-to-cut materials, like hardened steels and high temperature resistant alloys. The main advantage of the EDM process is the possibility of machining all electrical conductive materials, independent of the materials' mechanical properties like hardness and E-module [1]. Moreover, EDM provides high geometrical complexity, high form accuracy and high surface quality. These characteristics guarantee the sustainability of the EDM-Technology in the future [2]. The technology can also be used for producing micro-components because of the nearly non-existing machining forces.

2 Experimental Investigations

The investigations were carried out at Fraunhofer IPK in cooperation with the machine tool manufacturer Zimmer&Kreim GmbH Co. KG from Brensbach, Germany. The aim of the project was the optimization of EDM-Technology for achieving smooth surfaces in tool steel through the employment of optimized machining parameters.

2.1 Experimental Set-up

The tool electrodes used in the investigations are made of Electrolyte-Copper E-Cu 58 (electrode surface area of 2.25 cm^2), widely used in the mould industry when the objective is the achievement of smooth surfaces. As workpiece material the hardened steel 1.2344 (X40CrMoV5-1) was applied and this is used by the plastics industry as tool for the replication of parts using injection moulding technology. IonoPlus from Oelheld, Germany, was used as dielectric fluid.

The machine tool Genius 1000 THE CUBE was used in these investigations. This machine tool possesses two distinct discharge generators: a static impulse generator and a relaxation generator (O-Module), which enables very short discharge duration through capacitor discharge. In the investigations described here, the static impulse generator was used for the finishing process, while the relaxation generator was applied for the final polishing of the surfaces. The experimental set-up is sketched in Figure 1.

2.2 Parameter Study applying DoE-Methods

The first conducted experiments have as aim the determination of main influencing parameters as well as the interaction between them on the polishing process. Therefore the DoE-Method (Design of Experiments) was used in the first phase. Six machining parameters were chosen to be investigated during the polishing process. These parameters were the following: machining time t, machining time between flushing intervals t_{ero}, pause duration t_0, ignition current I, pulse duration t_i and capacitance C_e. A cavity depth of 200 µm was first produced using finishing parameters, followed by the polishing stage. The finishing parameters were kept constant during the trials. In the polishing process the total machining time t is set at the machine tool instead of a cavity depth. The pre-experimental state of the art results produced a surface roughness Ra = 173 nm. For that, following parameters were used: t = 60 min, t_{ero} = 1 s, t_0 = 2 µs, I = 0.1 A, t_i = 3 µs and C_e = 1 nF.

The analysis of the results presented in Figure 1 show that the main influencing factors are the capacitance (high significance) as well as the machining time between flushing intervals (small significance). The other four parameters had, at this time, no significance on the achieved average surface roughness Ra. The analysis of a few distinct diagrams like Figure 1 allowed for carrying out optimization trials by varying directly the main influencing parameters. This enabled the achievement of smooth surfaces with a restricted total number of trials.

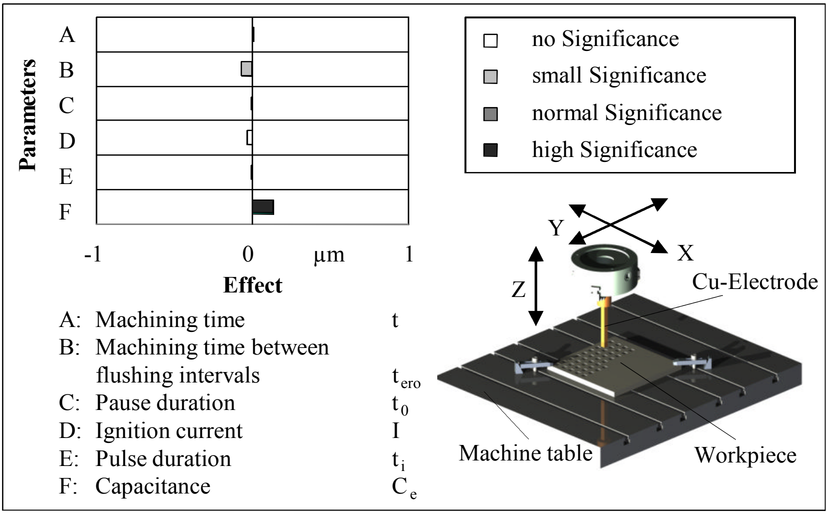

Figure 1: Significance of the parameters in the first experiments and sketch of the experimental set-up

2.3 Results

After the understanding regarding the effect of the main influencing parameters on the expected results, four optimization loops were carried out. The best results achieved are presented in Figure 2 and these comprise an average surface roughness Ra < 100 nm for four samples. In the best case, an average surface roughness Ra = 85 nm was achieved and this is equivalent to a surface ratio of F = 26.5 (electrode area in cm² divided by average surface roughness Ra in µm).

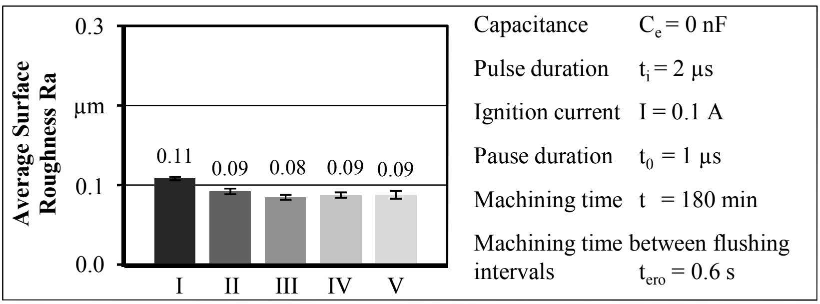

Figure 2: Average surface roughness Ra of five distinct samples

Finally, the affected sub-surface was analysed for thickness and crack formation by using scanning electron microscope (SEM). The results are presented in Figure 3. The thickness of the affected sub-surface was less than 2.01 µm and no crack formation could be observed on the samples.

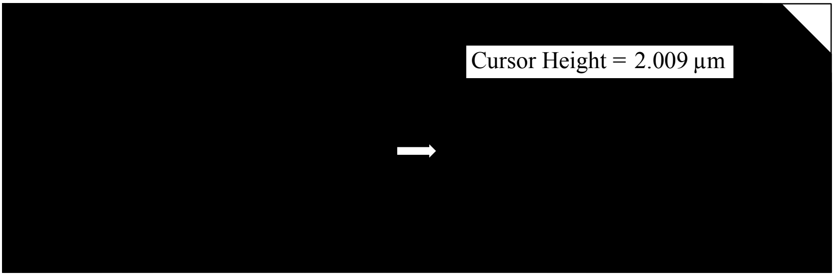

Figure 3: Sub-surface analysis through scanning electron microscope SEM

3 Summary and Outlook

A technology for the reproducible production of smooth surfaces was developed and presented in this paper. An average surface roughness Ra = 85 nm was achieved for the 2.25 cm^2 surface and this is equivalent to a surface ratio F = 26.5. The reproducibility of the experiments has been verified by the realization of five cavities using the same process parameters. The relaxation generator of the machine tool applied in these experiments showed that very smooth surfaces can be produced in hardened steels, even for the surface area machined. This effect can be attributed both to the generator as well as to the translational speed of the z-axis (18 m/min), which allows for optimized flushing conditions for the usually very small gaps found in polishing process. No cracks have been observed on the surface of the tested samples and these showed an affected sub-surface less than 2.01 µm in thickness.

References:

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