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An experimental framework for micro-EDM texturing on ceramic injection moulds for improved feedstock flowability

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Abstract

Micro ceramic injection moulding is a commonly used replication method for mass production of ceramics parts of complex shapes with tight tolerance. However, improving the wear resistance of moulding surfaces as well as enhancing the injection feedstock flowability is a challenging task for ensuring the homogeneous productions. To resolve this challenge, micro-EDM based surface structuring of the STAVAX steel mould has been put forward in this paper. Conventionally, short and ultra-short pulsed laser micromachining are used for texturing. However, the beam based methods (lasers) have limited control on dimple shape and dimensions. Femto-second lasers have proven in demonstrating better dimensional control of textures but the processing speed becomes low. Furthermore, reflectivity issues on the curved and polished mould surfaces limit texturing performance. Therefore, micro-EDM is put forward as a tool-based texturing method to achieve better control over dimple shape and dimensions. A large amount, i.e. 2500, of micro-dimples were textured along the 100 mm spiral channel, which is used for the injection flowability test. Before machining, micro-EDM tool path planning along a spiral trajectory planning has been generated. The structured surface topology has been characterized together with a statistical analysis of the frontal tool wear. The spiral flow test has showed the effectiveness of applying micro-EDM in structuring the complex injection mould.

Micro-EDM, surface texturing, micro ceramic injection moulding

1. Introduction

Being an efficient method for enhancing the surface functionalities, EDM based surface texturing has been reported in reducing the injection adhesion and friction and thus improving the micro injection moulding productivity [1,2]. The micro-structures such as micro-dimples reduce the contact area of liquid–solid (feedstock-mould) interface as well as the air gets entrapped in these dimples which ultimately reduces coefficient of friction and hence the flowability of feedstock can be improved. There are several micro-machining technologies, such as laser micromachining, micro electrical discharge machining (EDM) and micro-cutting, which can be used for producing the micro-structures. Among them, micro-EDM has as the capability of generating geometrically controllable features in the micro-meter scale on difficult-to-cut materials, together with controllable material damage around the feature. Therefore, this paper focuses on structuring of mould cavities with micro-dimples by employing micro-EDM assisted with a wire electrical discharge grinding (WEDG) unit for dressing micro-electrodes down to 30 µm.

2. Materials and methods

2.1. Trajectory planning

The spiral mould was made out of STAVAX® steel. It consisted of a spiral channel fabricated by milling and a tapered hole in the center for injecting the pressurized feedstock into the mould. The objective was to structure the spiral mould surface with micro-dimples using micro-EDM technology.

The nominal diameter of the dimples is 30 µm and the nominal depth is 30 µm. The nominal pitch between any two dimples along the spiral path is considered to be 200 µm while the pitch of two dimples tangent to the spiral path is specified to be 150 µm. In order to define the tool motion along the spiral groove, a fully automated program was developed in Matlab® by using the Archimedean spiral in a parametric form

$$\begin{aligned} r &= \frac{R}{n\times 2\pi}\theta \\ x &= x_0 + r\cos(\theta+\theta_0) \\ y &= y_0 - r\sin(\theta+\theta_0) \end{aligned} \tag{1}$$

where n refers to the turns of the spiral and is specified as 3. θ_0 is the angle between the starting point and end point. $\theta \in [0, n*2\pi]$ denotes the spiral rotation angle. r denotes the spiral radius with respect to the rotation angle. x_0 and y_0 denote the spiral center position located in x- and y- axis respectively.

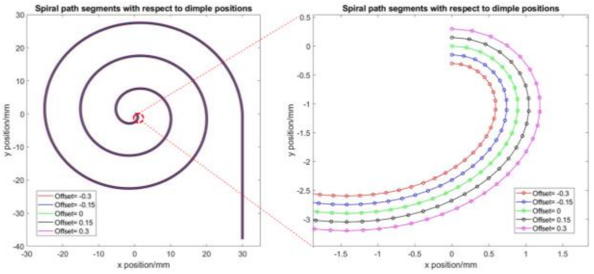

Figure 1. Equidistant spiral path generation through Matlab®.

The generated spiral path is shown in Figure 1, where five columns of equidistant spiral path segments have been simulated. The nominal distance between two consecutive spiral path segments is 150 µm.

2.2. Experimental set-up

The micro-EDM structuring experiments were conducted on a SARIX® SX-100-HPM machine. The clamping was achieved by fixing the spiral mould on a conductive block using bolts and the assembly was further clamped on a vise on the machine-bed as shown in Fig.2(b). The micro-EDM milling tool followed the trajectory generated from delivered positions as explained in section 2.1. In order to fabricate the micro-dimples down to 30 µm in diameter, the WC electrode was dressed using the on-machine wire-electric discharge grinding (WEDG) set-up as shown in Fig.2(a). A finish-machining regime was utilized for micro-EDM strcuturing of each dimple assisted with the side injet flushing (HEDMA oil) covering along the entire channel during the process. Based on the experimental experience gained from pilot experiments, the main electrical parameters for fabricating micro-dimples on STAVAX® steel mould were set as, e.g. pulse frequency= 170 kHz, open voltage= 90 V, current index= 70, servo voltage= 65 V. The spiral mould was made of Stavax® steel and the feedstock for spiral flow test was polyoxymethylene (POM) binder with Zirconia particles.

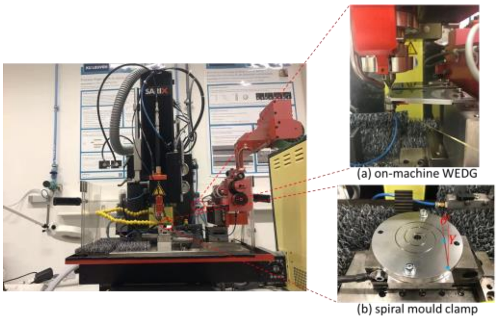

Figure.2 micro-EDM set-up for micro-dimples texturing. Zoom-in figures shows (a) WEDG set-up and (b) the clamping of spiral mould on a vise

3. Results and discussion

The dressed electrode is shown in Figure 3. Its diameter is 30 µm with a tolerance of 1 µm and the dressed length is 3 mm. A trapezoidal transition is designed between the parent rod and the dressed rod. This is specifically achieved to strengthen the stiffness in this transitional part.

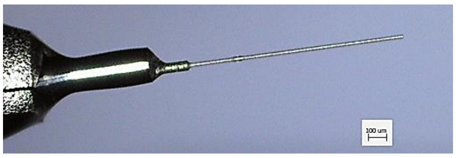

Figure 3. The dressed electrode by WEDG unit. Image acquired through a digital microscope (Dino-Lite® Edge AM4115ZT)

The spiral channel with the micro-dimples is shown in Figure 4(a). Analogous to the simulated segments (section 2.1), one row of dimples were observed equidistant while one column were shown along the channel. Figure 4(b) shows the profile of a representative micro-dimple fabricated by micro-EDM, where the colorbar represents the height values. The profile gives a conical appearance instead of straight-walls due to the inevitable corner wear worn on the dressed electrode. This excessive tool wear is caused by the accumulated sparks near the sharp edge of the electrode where the electrical field intensity is comparatively high. And the corner wear is substantial in size for the micro-electrode leading to the evolvement of a conical shape in the electrode tip. This usually occurs under the condition of a small machining depth where the sparking difference in field was not able to be eliminated in time. The target machining depth was pre-defined as 30 µm while the achieved dimple depth (Figure 4(c)) is measured as 20 µm. The difference in depth is attributed to the frontal wear of the electrode. However, the frontal wear, especially in micro-meter scale, is difficult to be precisely controlled due to the inconsistent machining condition and the probabilistic sparking phenomena of micro-EDM. This is also presented in the statistical results (Figure 5), of frontal wear with respect to 100 runs of micro-dimples near the entry, in the middle and near the end of the channel. The average frontal wear in the middle is slightly higher than that near the entry and the end, which might be due to the non-uniform flow-field along the spiral channel.

The spiral flow tests were conducted at Formatec® company with and without surface-structuring. The spiral flow length with micro-EDM texturing is measured as 86.85 ± 1.68 mm while the it is only 68.05 ± 1.46 mm without texturing. This indicates a 27 % increase in feedstock flowability with micro-EDM structuring.

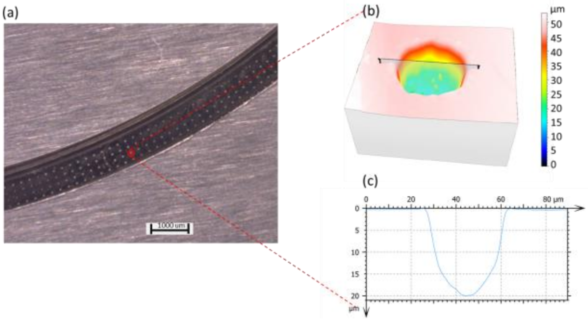

Figure 4. Textured dimples by micro-EDM on the spiral channel. (a) Optical image of the textured segment of the whole spiral channel (b) A representative dimple topology (measured by SENSOFAR® S NEOX) (c) cross-sectional profile of a representative dimple.

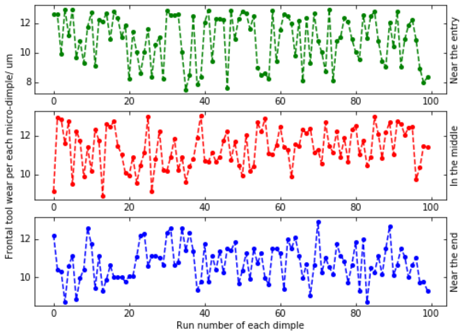

Figure 5. Frontal tool wear with respect to 100 runs of micro-dimples. These three sub-figures, from the top to the bottom, show the statistical results measured near the entry, in the middle and near the end of the spiral channel, respectively.

4. Conclusions and outlook

This paper detailed the micro-EDM texturing steps: micro-EDM tool trajectory planning, workpiece clamping, parameter setting, tool-electrode dressing and fabrication of micro-dimples. The topology of a representative micro-dimple appeared as a smooth conical shape due to corner wear of micro-electrode. A 27 % increase in feedstock flowability with micro-EDM structuring has been observed in spiral flow-tests.

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