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Wire electrical discharge grinding of micro rods for bonding-free fabrication of soft pneumatic microactuators

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Abstract
This paper presents the machining process of tungsten carbide micro rods using wire electrical discharge grinding (WEDG). The micro-rodes are used in the bonding-free moulding process of soft pneumatic microactuators. First, a multi-step cutting strategy including roughing and finishing is described. Second, two sets of grooves of different depths are WEDGed into the micro rods. Based on the concept of interconnected pneumatic networks, the machining of micro rods would enable the fabrication of soft pneumatic microactuators in which bending motion is concentrated on specific sections when they are pressurised.

Wire electrical discharge grinding (WEDG), micromachining, microactuators, soft robotics

1. Introduction

Soft pneumatic microactuators have been introduced in a wide variety of soft robotics applications, including minimally invasive surgery, assembly of micro components and micro total analysis system (µTAS). These microactuators, which essentially consist of an elastomer-based structure surrounding an inner void chamber, can achieve large strokes when the void chamber is pressurized. Unlike the various microactuators that were developed through the past years [1], this paper focuses on microactuators of cylindrical shape (Figure 1a) where the actuation is achieved through the asymmetry design of the inner void chamber (Figure 1b). A micro moulding process was recently demonstrated to manufacture this type of advanced soft pneumatic microactuators. One advantage is that it does not require any bonding step to create the void chamber [2]. In this process, a cylindrical micro rod is positioned eccentrically into a hollow cylindrical cavity that is later filled with liquid polymer. After polymerisation, the result is a microactuator with a void chamber that has the negative shape of the cylindrical micro rod. That feature enables the fabrication of more complex void chamber. Indeed, bespoke void chanber can be created by varying the shape of the micro rod.

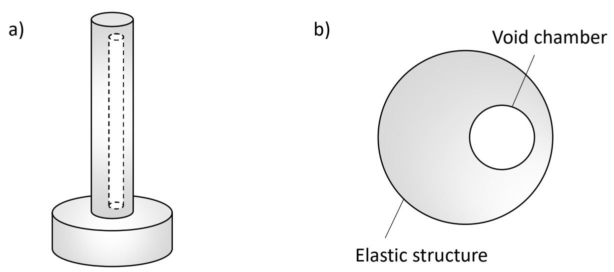

Figure 1. Geometry of a soft pneumatic microactuator: a) 3D view, and b) cross section showing the asymmetry of the void chamber.

This paper presents the machining process of micro rods. The aim is to introduce new geometries of the void chamber. The geometries are obtained by machining grooves into rotating cylindrical micro rods using wire electrical discharge grinding (WEDG). A multistep machining strategy for creating axysimmetric grooves into the micro rods is firstly created and optimised. Then, based on pneumatic network design concepts [3], the fabrication of micro rods of two different shapes is proposed by combining grooves of equal heights but different depths.

2. Methodology

The experiments were carried out using the WEDG unit of a SARIX® SX-100-HPM micro-EDM machine. Tungsten carbide cylindrical rods of 500 µm nominal diameter (Figure 2) were chosen. The WEDG unit was equipped with a brass wire. The diameter of the wire (D_{wire}) was 200 µm. Hydrocarbon oil of viscosity equal to 2.4 cSt at room temperature (HEDMA® 111) was used as dielectric fluid.

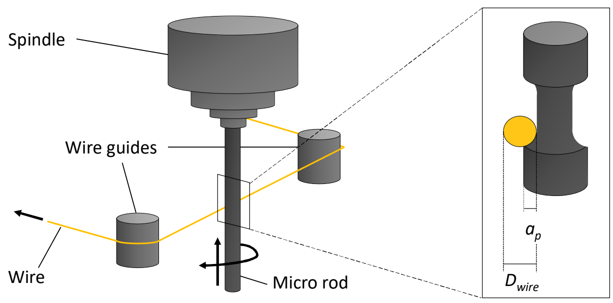

Figure 2. Sketch of the WEDG process of the micro rods. The close view highlights the wire diameter (D_{wire}) and the depth of cut (a_p).

To decrease the machining time, WEDG processing was carried out through two regimes: roughing and finishing. Positive polarity was applied in both cases. Preliminary experiments were perfomed on the micro rods to determine the optimal depth of cut (a_p) that maximises the material removal rate (MRR) during the roughing regime. Table 1 displays the process parameters corresponding to each machining regime.

Table 1 . Processing parameters.

Parameter	Roughing	Finishing
Open voltage u_0 [V]	120	85
Capacitance C [nF] *	5	1.5
Pulse duration T_{ON} [µs]	5	4
Pulse interval T_{OFF} [µs]	3	2
Reference voltage u_e [V]	85	72
Spindle rotation [rev/min]	850	700

*estimated

Benchmark grooves of 1.5 mm height were repeatedly machined. To compute the MRR, the machining time was measured, the machined sections were measured and the unmachined volume was estimated. The diameters of the machined profiles were measured by a Sensofar® S lynx microsope. On the contrary, since only a single finishing machining step was applied, a finishing a_p equal to 10 µm was selected without performing any optimisation study.

Once the optimal roughing a_p was determined and the finishing step was demonstrated improving surface quality, the machining strategy was applied to machine two specific sets of grooves into micro rods. These two sets of grooves were chosen to investigate dimension variations of the void chamber.

3. Results and discussion

The results showed that a depth of cut equal to 20 µm should be used for roughing the axisymmetric grooves. Figure 3 displays that MRR increases for a_p in the range 5 to 20 µm, while MRR decreases when a_p increases further. The overall trend of the MRR can be explained by the fact that the increase of the machining time is significantly higher than the increase of the volume of removed material with a_p, due to worsening of flushing conditions and limitation in the unit of removed material per discharge.

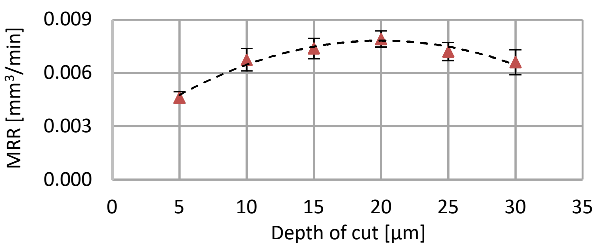

Figure 3. Effect of depth of cut on material removal rate (MRR). Mean values and ranges after 3 repetitions of the experements are shown.

The analysis of the surface morphology of the machined sections of the micro rods carried out by means of a scanning electron microscope (SEM) revealed the benefit of the single-step finishing after roughing. In particular, a less uneven surface morphology was achieved once the single-step finishing was performed after roughing (Figure 4). This difference in surface morphology resulted in a decrease of the surface roughness from S_a = 0.84 µm to S_a = 0.37 µm, as assessed from 20 samples measured on 10 grooves by a Sensofar® S lynx microscope.

Figure 5 displays two micro rods featured with different sets of grooves of constant height (1.5 mm). The micro rod (Figure 5 top) was machined by repeating eight grooves of 50 µm depth and leaving a gap of 0.5 mm between each groove. The micro rod (Figure 5 bottom) was done by machining consecutive grooves of depths respectively equal to 50, 75, 100, and 125 µm. The last groove of 125 µm depth was repeated twice.

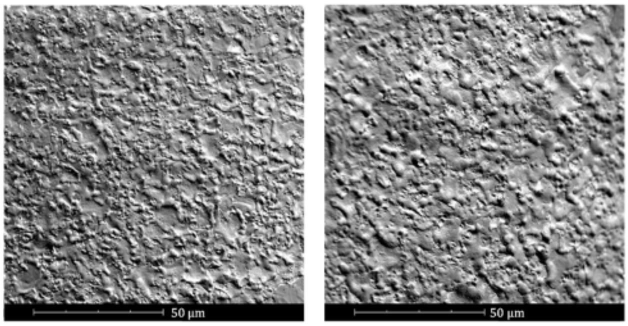

Figure 4. Surface morphology after (left) and before (right) the finishing step. The images are taken by a Phenom® Pro SEM microscope.

Based on the previous results, a maching strategy consisting of multiple cutting steps at a_p=20 µm and a finishing step at a_p=10 µm was applied. In the cases where the groove depth was not achievable by multiple steps of 20 µm, the depth of cut of last roughing step was appropriately modified to meet the desired groove depth. Measurements of the grooves of 50 µm depth on five micro rods have shown an accpetable repeatability of 2.68 µm standard deviation. The presence of a systematic error (5.23 µm deviation between nominal groove depth and average measured depth) should be corrected in the future.

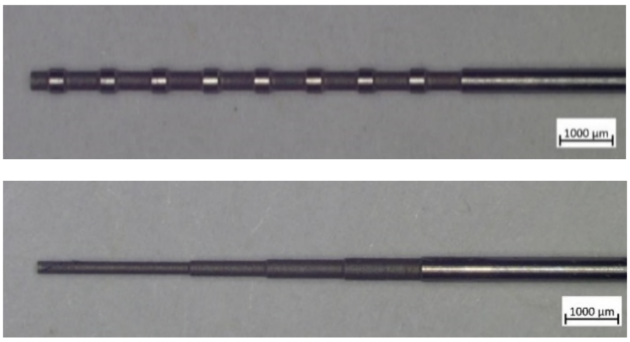

Figure 5. Machined micro rods to introduce pneumatic networks in soft pneumatic microactuators. The images are taken by means of a ZEISS® SteREO Discovery V20 microscope.

4. Conclusions

The machining of tungsten carbide micro rods using WEDG to introduce pneumatic networks in bonding-free fabricated soft pneumatic microactuators was presented in this paper. The developed machining strategy can be easily adapted to create axisymmetric grooves of different depths and heights than the ones machined here, also on micro rods of different diameters. Characterisation of the microactuators that were fabricated is currently carried out. The objective is to investigate the difference in bending motion when introducing a pneumatic network and to eventually optimise the design of the void chamber.

References

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