euspen's 22nd International Conference &
Exhibition, Geneva, CH, May/June 2022
www.euspen.eu

Soft machines for force-free micromachining processes

Elias De Smet[1,2], Krishna Kumar Saxena[1,2,*], Muhammad Hazak Arshad[1,2], Laurens Thielman[1], Benjamin Gorissen[1,2], Dominiek Reynaerts[1,2]

[1]*Micro -& Precision Engineering Group, Division Manufacturing Processes and Systems (MaPS), Department of Mechanical Engineering, KU Leuven, Belgium.*
[2]*Member Flanders Make (https://www.flandersmake.be/nl), Leuven, Belgium.*

*krishna.saxena@kuleuven.be

Abstract

The compliance, light weight, fast actuation and flexibility in positioning of soft-actuators makes them interesting candidates for force-free micromachining processes such as electrochemical machining (ECM) and electro-discharge machining (EDM). Electrochemical machining in particular has high potential to be integrated in soft-machines as it does not involve machining forces and is absent of tool wear. In this paper, preliminary research work is presented on the development of a soft actuator with a conductive element to be used for electrochemical machining applications. The design and development of the soft-actuator is presented along with proof-of-concept electrochemical machining on the inside of a prototype cylindrical workpiece.

Keywords: Micromachining, Electrochemical Machining, ECM, soft-actuators, soft-machines

1. Introduction

With the advancement in soft-robotics and soft-actuators, the development of soft-machines at different length scales has opened up new avenues of applications [1]. The compliance, light weight, fast actuation and flexibility in positioning makes them interesting candidates for force-free micromachining processes such as electrochemical machining (ECM) and electro-discharge machining (EDM). Electrochemical machining [2] in particular has high potential to be integrated in soft-machines as it does not involve machining forces and is absent of tool wear. ECM process can machine conductive materials without any limitation on the hardness.

The development of soft-machines will help in minimizing the use of multiple motion-axis [3][4] and their complex control softwares in ECM machine-tools. On top of that, it will also reduce the efforts needed to design complicated tools for the machining of features at difficult locations on the workpiece such as corners, bends, narrow-spaces, bearing races, spacing between gear teeth, internal features, etc. This will bring down the machine-tool and tooling costs and can reduce the size of machine-tools making them more portable. In order to realize the application of soft-machines in the field of micromachining, several challenges need to be adressed such as designing actuators with tuneable stiffness, embedding conductive elements, selecting an actuation method and control technique, as well as improving the positioning accuracy.

In this paper, preliminary research work is presented on the development of a soft actuator with a conductive spring element to be used for electrochemical machining applications. The design and development of a soft-actuator is presented along-with proof-of-concept electrochemical machining on the inside of a prototype cylindrical workpiece.

2. Design of the soft actuator

The actuator was designed keeping in account the requirements of electrochemical micromachining. Figure 1(a) shows the designed soft actuator. The actuator (33 x 19 mm) has a varying cross section along the length, with a slit in the middle containing a conductive spring element. The electrolyte enters into the actuator from the open end and continues into the interelectrode gap (IEG) via 4 channels (diameter: 0.82 mm) on the periphery of actuator as shown in Figure1(b).

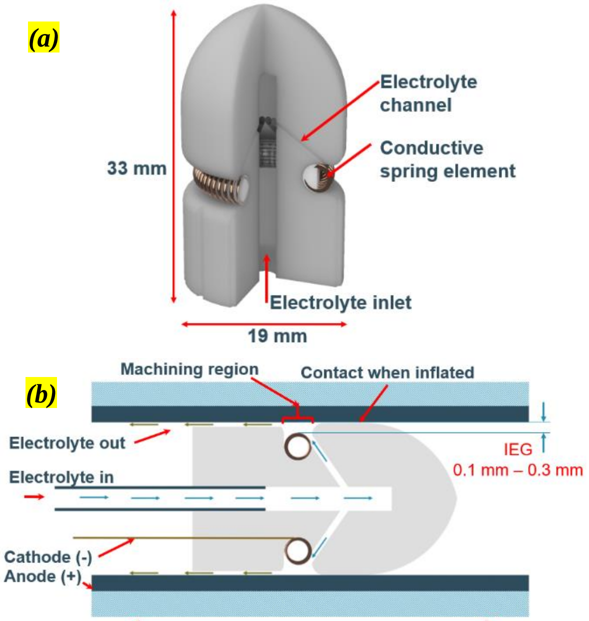

Figure 1. (a) Designed soft-actuator (b) Schematic of the electrochemical micromachining process with soft-actuator inside a cylindrical workpiece. IEG refers to interelectrode gap between the cathodic tool and anodic workpiece.

The spring element serves as the cathodic tool-electrode for the ECM process. In this design, the electrolyte serves dual function. It is used as a working fluid for the electrochemical machining process as well as a fluid to control the inflation of the actuator. Figure 2 shows the result of the FEM simulation (Abaqus® software, hyperelastic material model) of the deformation of the soft actuator after inflation. It can be observed that the IEG required for an ECM process is set automatically when the inflated actuator touches the walls of the workpiece.

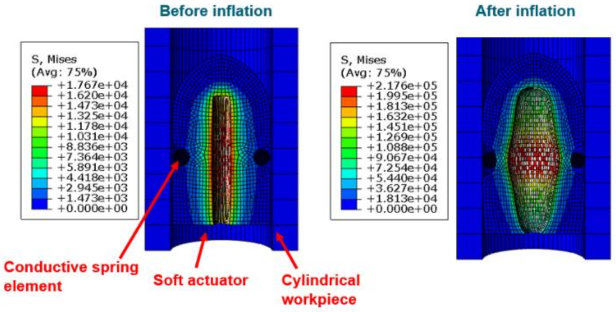

Figure 2. Simulation of the deformation of the actuator after inflation inside the cylindrical workpiece using Abaqus® software.

Simulation results reveal that during inflation at pressure (p)=38694.4 Pa, the volume of actuator increases by about 6.8 times. As a result, the conductive spring element moves 0.5 mm outward and comes into contact with the pipe. Increasing the pressure after this point pushes the spring harder against the cylindrical workpiece, since the cylindrical workpiece obstructs any further radial displacement. Friction between the actuator and the internal surface of the workpiece hinders vertical displacement of the former, restricting the area where ECM occurs.

3. Manufacturing of soft-actuator

The soft-actuator is cast out of Ecoflex® 30 silicone rubber using two 3D printed PLA mould halves (Fig. 3(a)). First, needles are inserted into the moulds to later obtain the channels needed for electrolyte flow from inside the actuator to the machining region (Fig. 2). Next, both mould halves are filled by pouring liquid silicone rubber into them, and are then pressed together (Fig. 3(b)). After that, a metal rod is inserted into the center of the mould, creating the cavity through wich electrolyte will be supplied into the actuator. Then, the silicone is left to cure inside the mould until solid, after which the needles and rod are withdrawn from the mould and the cured silicone is cast out. Finally, the metal spring is mounted onto the cured soft-actuator, and an electrolyte supply tube is attached. Figure 3(c) shows first prototype of the produced soft-actuator.

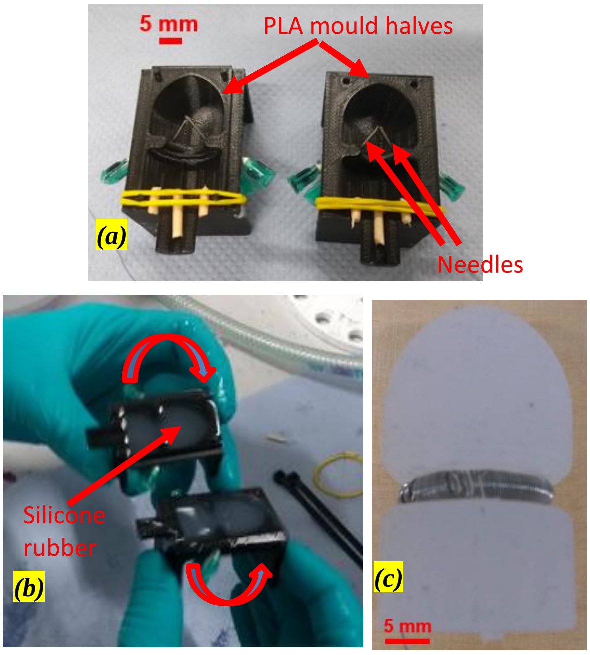

Figure 3. (a) 3D printed mould of PLA (polylactic acid). (b) Two halves of the mould filled with silicone (Ecoflex® 30) (c) First prototype of a produced soft actuator.

4. Proof-of-concept machining results

Pilot machining experiments were done on an Inconel IN718 workpiece using 20% aq. NaCl (sodium chloride) as electrolyte. The main machining parameters were voltage: 20 V, electrolyte flow rate: 1.4 ml/s, interelectrode gap ranging from 0.1 – 0.3 mm and the duration of machining was 20 s. Figure 4 shows a representative picture of the electrochemically machined Inconel IN718 workpiece using conductive spring element in the soft-actuator.

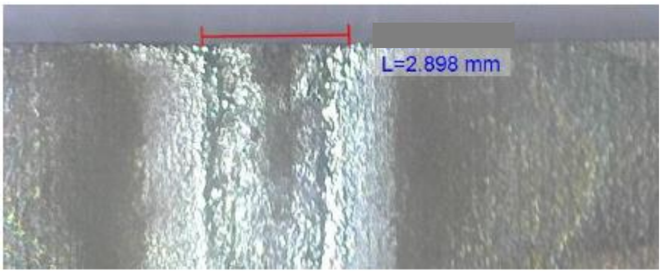

Figure 4. Proof-of-concept electrochemical machining using conductive spring element on an Inconel IN718 workpiece.

5. Summary

This work explores the intersection of soft-machines and force-free machining processes to explore novel applications of soft-robotics in the manufacturing field. In this direction, a first prototype of a soft actuator (33 x 19 mm) with a conductive spring element is designed to be used for electrochemical machining applications. The design and production of the soft-actuator is presented along-with proof-of-concept electrochemical machining on an Inconel IN718 workpiece. Further work is planned for improving the design of the actuator along with perfoming extensive experiments on machining the internal surface of the cylindrical workpiece.

References

[1] B. Gorissen, D. Reynaerts, S. Konishi, K. Yoshida, J. W. Kim, and M. De Volder, “Elastic Inflatable Actuators for Soft Robotic Applications,” *Adv Mater.*, vol. 29, no. 43, 2017, doi: 10.1002/adma.201604977.

[2] K. K. Saxena, J. Qian, and D. Reynaerts, “A review on process capabilities of electrochemical micromachining and its hybrid variants,” *Int. J. Mach. Tools Manuf.*, vol. 127, pp. 28–56, 2018, doi: 10.1016/j.ijmachtools.2018.01.004.

[3] Z. Suo, “Mechanics of stretchable electronics and soft machines,” *MRS Bull.*, vol. 37, no. 3, pp. 218–225, 2012, doi: 10.1557/mrs.2012.32.

[4] Y. Alapan, A. C. Karacakol, S. N. Guzelhan, I. Isik, and M. Sitti, “Reprogrammable shape morphing of magnetic soft machines,” *Sci. Adv.*, vol. 6, no. 38, 2020, doi: 10.1126/sciadv.abc6414.