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Micro product and process fingerprints for zero-defect net-shape micromanufacturing

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Abstract
Highly miniaturized systems find applications in key technological fields such as health-care, mobility, communications and optics. Required innovations for precision manufacturing of micro components can be achieved through post-process and in-process measurement of process input and output parameters. Hence, it is of critical importance to reduce the measurement and optimization effort, since process and product quality control can take a significant part of the production time in micro manufacturing. To solve this challenge, research is undertaken in order to define, investigate, implement and validate the "Product/Process Micro Manufacturing Fingerprint" concept. In particular, in the Horizon2020 Innovative Training Network "Process Fingerprint for Zero-defect Net-shape MICROMANufacturing", 9 beneficiaries and 14 industrial partners are collaborating to establish this concept for several manufacturing technologies, such as micro injection and micro ultrasonic moulding, micro mechanical and micro plasma polishing, micro electrical discharge machining, micro electrochecmical machining, micro grinding, micro laser machining, micro extrusion, micro metrology, micro sintering. The project has reached its goals of developing novel methods in micro scale manufacturing process monitoring and control, as well as micro and sub-micro product quality assurance. The overall result has been the establishment of effective micro product and process fingerprints for the considered manufacturing technologies.

Micro and nano manufacturing process chains, micro and nano metrology, process monitoring and control, micro production quality assurance

1. Introduction

The continuous trend towards further miniaturization of products relies on the availability of mass manufacturing processes for the production of micro systems. Micromanufacturing technologies are developed with the aim of producing miniaturized components in high volumes and in a cost-effective way. As such, micromanufacturing plays a central role in numerous engineering sectors [1]. As critical dimensions are scaled down, the complexity of micro parts increases. Moreover, tolerance ranges become much tighter than for macro-sized parts, posing challenges with respect to process optimization and compliance verification. To tackle these challenges, measuring instruments, such as atomic force microscopes, micro coordinate measuring machines, micro computed tomography and high-resolution optical 3D microscopes are available to deal with miniaturized components. However, there is significant room for improvement in the field of quality assurance of micro parts, particular during production. Current industrial practice is based on the use of off-line systems, which cannot be used to carry out quality assurance on all the manufactured parts, as the manufacturing time is typically shorter than those of the measurements.

In this scenario, the European Horizon 2020 MICROMAN project ("Process Fingerprint for Zero-defect Net-shape MICROMANufacturing" [2]) aimed at improving most of the existent micromanufacturing processes by finding innovative solutions based on the product/process fingerprint concept. In particular, the objective was to implement in-line quality assurance and optimization strategies for micromanufactured components by extensively applying process monitoring techniques. The MICROMAN project included 9 beneficiaries and 14 industrial partners and funded a total of 13 Early Stage Researcher (ESR) positions in Europe. Each ESR project focused on the determination and evaluation of the micro product/process fingerprint for a specific micromanufacturing technology. The investigated manufacturing technologies were: micro injection and micro ultrasonic moulding, micro mechanical and micro plasma polishing, micro electrical discharge machining, micro electrochecmical machining, micro grinding, micro laser machining, micro extrusion, micro metrology, micro sintering.

2. Product/process fingerprint concept

The novel approach introduced by MICROMAN is based on the process and product manufacturing fingerprint concept. The two are defined as:

- Product fingerprint: a specific dimensional outcome that is sensitive to process variations and correlated to the overall quality of the micro part. By controlling it, the conformance to specifications of all tolerances can be achieved.
- Process fingerprint: a process variable strongly correlated to the part quality and controllable in-line during manufacturing via suitable sensors. The value of the process fingerprint can be measured at each cycle, giving valuable indications without the need for additional off-line measurement procedures.

The objective of the project was to combine the two concepts in order to implement real-time process control aiming at zero-defect manufacturing. Once the two fingerprints are identified, a closed-loop process can be established, thus eliminating the need for time-consuming off-line measurement tasks and consistently shortening the process optimization phase. To design and implement a process/product fingerprint concept, an extensive experimental campaign must be carried out, followed by a robust statistical analysis with the aim of identifying the most suitable fingerprint variables (see Figure 1).

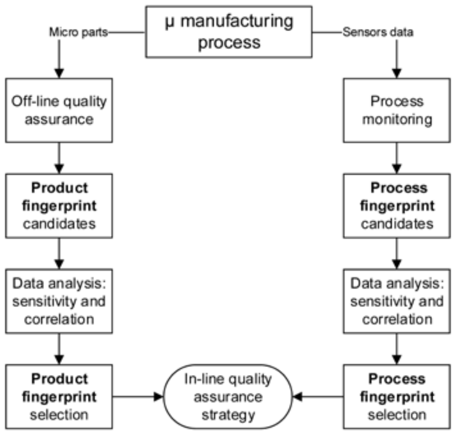

Figure 1. Flowchart representing the method to identify product and process fingerprints leading to the definition of an in-line quality assurance strategy.

3. Case study: micro injection moulding

The aforementioned procedure was successfully applied to a 3D micro plastic component produced by micro injection moulding (µIM) [3]. The component had a nominal mass of 0.1 mg, was made of polyoxymethylene (POM) and was moulded using a state-of-the-art Wittmann-Battenfeld MicroPower 15 µIM machine. The produced parts were assessed off-line using a focus variation optical instrument. Two process variables were recorded in-line: the pressure and the velocity of the injection plunger, which were both derived from the machine data. Suitable process variables, e.g. maximum pressure, integral of pressure, average pressure, etc., were extracted from each in-line monitoring cycle and correlated to part quality to identify the best process fingerprint candidate.

The results of the analysis showed that the best product fingerprint candidates critical for part quality were the size of the gate mark, which was quantified with its length L_{mark}, and the area of the flash at the bottom of the component A_{flash}. On the other hand, the mean integral of the injection pressure during filling, named $I_p/\Delta t$, was the most suitable process fingerprint, being highly correlated with the dimensional quality of the moulded component (see Figure 2). By controlling the identified process fingerprints, accurate control of the size of the defects can be performed: $I_p/\Delta t$ must be kept at values close to 400 bar as trade-off to minimize both gate mark and flash area. Since both L_{mark} and A_{flash} correlate with the overall quality of the micro part, the quality assurance procedures can be carried out by monitoring the selected process fingerprint, thus gaining valuable information on the outcome of the process without needing off-line and time-consuming inspection.

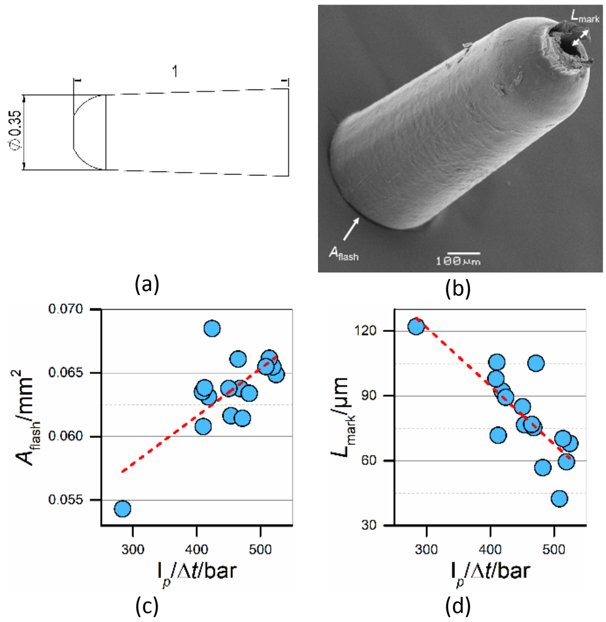

Figure 2. (a) Micro part main dimensions; (b) µIM part, gate mark and flash; (c) A_{flash} product vs process fingerprint; (d) L_{mark} product vs process fingerprint. The red dashed line represent the linear regression trend.

4. Conclusion

The MICROMAN project succesfully contributed to the advancement of micromanufacturing technologies by developing in-line quality control strategies based on the product/process fingerprint concept. In this paper, an example is given on the results related to a micro moulded plastic part, whose quality could be optimized and assured by monitoring the injection pressure value for each moulding cycle.

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References

[1] Brousseau EB, Dimov SS, Pham DT 2010 Some recent advances in multi-material micro- and nano-manufacturing *Int. J. Adv. Manuf. Technol.* **47** 161–80

[2] http://www.microman.mek.dtu.dk/

[3] Baruffi F, Calaon M, Tosello G 2018 Micro-injection moulding in-line quality assurance based on product and process fingerprints *Micromachines* **9**