euspen's 18th International Conference & Exhibition, Venice, IT, June 2018

www.euspen.eu

High precision electrochemical manufacturing processes to meet the demand of Industry 4.0

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Abstract

Manufacturing industry is facing new challenges as there is a growing demand for mass-personalized products. A new kind of processes need to be developed. A major hurdle to overcome for successful production of mass personalized products are setup and tooling costs. Suitable manufacturing processes for personalized batch-size-1 production must be highly flexible and have little overhead. Hybrid technologies are very promising as these processes require little to no specialized tooling and can handle virtually any shape, including inner surfaces.

In the present communication, it is shown how electrochemical processes can be used to design high precision manufacturing processes for Industry 4.0. Examples are discussed in the field of hard to machine materials like glass, post-processing technologies for metal AM parts and fabrication of high-precision complex metal structures based on 3D printed high resolution polymer models.

Industry 4.0; mass-personalization; batch-size-1; electrochemical manufacturing; electro-polishing; micro-machining; post-processing; electroforming; additive manufacturing;

1. Introduction

Manufacturing industry has to face a new trend: mass personalisation. Market pull driven by shorter life-time cycles, increased complexity and the demand for individualized products are main drivers. Mass personalization presents new challenges: economical production of small batch sizes is incompatible with established manufacturing systems designed to produce large quantities of identical parts. Recently a new paradigm appeared as answer and was termed in Germany in 2011 as Industry 4.0 [1]. The key idea is a new type of manufacturing systems, smart factories, in which manufacturing entities communicate via the Internet of Things allowing higher flexibility, quicker adaption to new designs and increased productivity [2,3].

A first step towards mass personalisation is mass customisation [4]. For such situations, smart factories are an excellent answer. In these cases, the shape of the sub-parts is essentially fixed and the final product is built out of individual modules. On the long run manufacturing industry will have to deal with situations where shapes of parts change too where the customer will not only choose from existing options but actively be involved in the design. In such cases (refered as mass personalization [5]) manufacturing processes of a new kind are needed which are able to keep manufacturing overhead related to change of part shapes low. In particular they have to be able to address the issues of tooling costs (avoid part specific tooling), able to handle complex parts and reduce production steps (as in each step parts will have to be transferred from one system to another resulting in overhead due to e.g. alignment or tooling).

Additive manufacturing (AM) appears to be one of such technologies and is cited in literature as the solution to mass personalization [6]. Tooling costs are small (the machine builds tooling during manufacturing) and complex shapes can be produced. As such, AM appears as one of the corner stones of Industry 4.0. However, besides presenting its own challenges, AM will likely not be the sole manufacturing technology on which industry will rely. Other technologies able to work together or independently to AM (e.g. for materials that cannot be printed well such as glass) will be needed.

Academia and industry just started to develop such technologies [7], but main research focus remain on AM and comparatively little work is conducted on alternate technologies. As highlighted in a recent case study made by the Universities of Michigan and Cincinnati for the World Economic Forum, hybrid technologies, in particular electrochemical technologies, would have a great potential towards this aim [8].

In the present study, it is shown how hybrid electrochemical processes can be used to design new high precision manufacturing processes for industry 4.0. Some examples are discussed in the field of hard to machine materials like glass, post-processing technologies for metal AM parts and fabrication of high-precision complex metal structures based on 3D printed high resolution polymer models.

2. High precision glass machining

The feasibility of a novel approach, using Spark Assisted Chemical Engraving (SACE), to manufacture personalized parts in glass, is presented. Key in this methodology is the use of low-cost rapid prototyping technology and an in-situ fabrication method for the needed tooling, eliminating indirect costs and reducing lead times. This approach can be used for on-demand manufacturing of personalized high precision applications of glass such as smart phone covers, Lab-on-Chip, green energy devices or fiber optic telecommunications.

2.1. Experimental setup and SACE principles

In SACE process (figure 1.A.), a voltage is applied between tool- and counter-electrode dipped in an alkaline solution [9]. At high voltages (around 30 V), the bubbles evolving around the tool electrode coalesce into a gas film and discharges occur from the tool to the electrolyte through it. Glass is machined by thermally promoted etching [9].

SACE has recently reached industrial maturity for mass-fabrication (figure 1.B.) [10]. Breakthrough was the implementation of a force-sensitive machining head allowing the use of ultra-thin machining tools (diameter down to 30 µm), applying force-feedback algorithms and usage of the head as profilometer to measure machined features within the same setup [11].

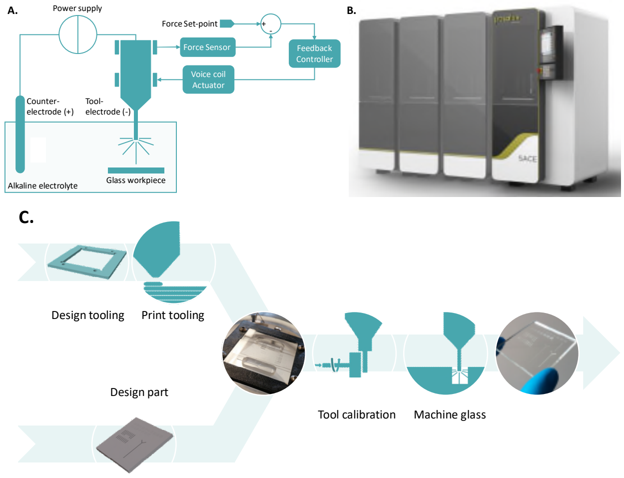

Figure 1. A. SACE process principle **B.** Developed industrial SACE machine [10]. **C.** Process steps for fabrication of a client-specific workpiece in glass by SACE technology.

2.2. Fabrication Process Cycle

An integrated approach is developed for fabrication of personalized glass devices by SACE (figure 1.C.).

The tooling, tool-electrodes (Ø=100µm) and adequate sample holders, is manufactured on demand by flexible processes to meet requirements of low-cost personalization. An advantage of SACE is the absence of high forces exerted on the tool and consequently the work-piece. Therefore, the tool-electrode can be fabricated on the same setup as used for machining the workpiece and the sample holder can be manufactured by low-cost AM, like Fused Deposition Modeling. The digital design file is used for programming the machining trajectory and for designing a 3D model of the sample holder. The proposed tool fabrication method calibrates the machine center as well, i.e. the tool is aligned relatively to the workpiece and run-out is reduced, eliminating the need of a costly high precision spindle or subsequent alignment after each tool change. This methodology allows significant reduction of setup times (about 60% compared to the conventional approach).

3. Additive Manufacturing

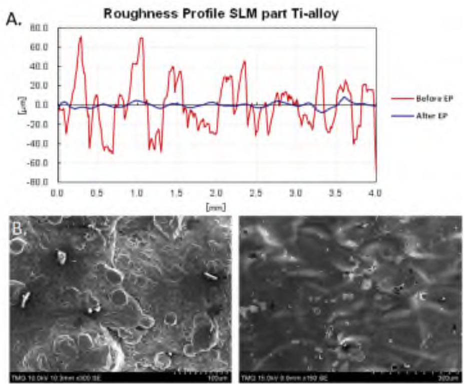

Figure 2. A. Roughness profile of a Ti-alloy workpiece before EP *(red)* and after EP *(blue)*. **B.** Electron microscopy images of workpiece surface before EP *(left)* and after EP *(right)*.

Advances in AM allow for high resolution fabrication of complex three-dimensional structures. Promising applications for this approach are biomedical implants, cooling channels inside molds for casting and lightweight parts for the aerospace industry.

However, major issues are the limited materials available for metal printing, limited quality in surface finish and the challenge of printing thin features (typically < 200 µm).

3.1. Post-processing Additive Manufactured parts

Post-processing metal AM parts with processes requiring low tooling and ability to reach inner surfaces is a challenge. Here, electrochemical technologies are a good candidate.

Electro-polishing (EP) is an effective way to eliminate surface asperities. A significant decrease in surface roughness could be obtained after EP of various materials (Ti6Al4V, AlSi10Mg and EOS PH1), as presented in figure 2. The team works as well to apply this post-process on metal AM parts with hard-to-reach and small inner surfaces.

3.2. Fabricating complex metal structures

Metal AM is not capable of printing ultra-thin features (typically < 200 µm) due to powder size. To address this issue, we propose a novel approach able to produce ultra-thin (down to few microns) and light metal parts of complex shapes. The process starts by printing a plastic part which is subsequently made conductive by electroless plating. In a next step, a part of controlled thickness and surface roughness can be created by electroforming. Dissolving the plastic part in a last step allows the creation of self-standing ultra-light metal parts with high surface finish and high complexity (figure 3).

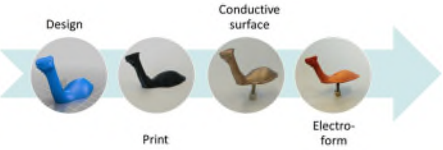

Figure 3. Process flow from design to metal part by electroforming

A second approach, currently under development in the team, is the fabrication of 3D metal structures (aspect ratios > 10) by localized electrochemical electrodepostion (figure 4).

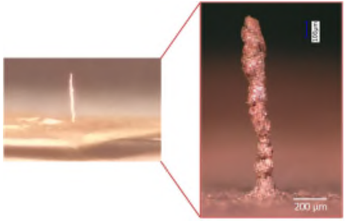

Figure 4. Copper pillar (hight = 1100µm, Ø < 100 µm) fabricated by localised electrochemical deposition.

4. Conclusions

It is shown that hybrid electrochemical processes can be used to design new high precision manufacturing processes for industry 4.0 requiring low manufacturing overhead.

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