Sensors integration in additive DMLS metal parts

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Abstract: The fabrication of metal parts by laser-based additive manufacturing (AM) processes is providing many applications in the medical field. The layer-by-layer growth of the component provided by powder micromelting allows, at least in theory, the incorporation of discrete sensors and wires inside the metal material. However, several process-related issues make this operation very challenging. This paper introduces the incorporation of thermal and inertial sensors inside 17-4PH steel specimens fabricated by DMLS (direct metal laser sintering) process (PCT/IB2019/053581, 02/05/2018). In the final configuration, the sensors are totally encased into the continuous metal parts with complete protection against contamination and tampering.

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I. Introduction

The integration of sensors into metal parts is of interest for many applications in the clinical and medical fields, for example for the monitoring of tools and instrumentation, prosthetic components and biomechanical parameters of patients. The traditional strategies for embedding sensors consist in drilling holes by milling, or using holders/cases, or by direct adhesive installation on the surfaces, or in other similar procedures. The spread of additive manufacturing (AM) processes opens to innovative procedures of sensors integration, especially about powder bed processes as direct metal laser sintering (DMLS) or selective laser melting (SLM), which provides the most stable and repeatable properties of metal parts. The challenges linked to this innovation are the preservation of sensors integrity during laser exposure of metal powder, the handling of sensors during the process, the exposure of metal reactive powders to environmental oxygen, and the preservation of metal part integrity. Other processes have been described in the past for sensors integration in AM-built parts but preferably with polymers or by technologies that do not involve laser power source. For instance, optical fibers were integrated into metal parts built with direct energy deposition (DED) [1] and into polymers with selective laser sintering (SLS) [2]. Pressure sensors were encapsulated into polymeric cylinders built with stereolithography (SLA) [3] for monitoring fluid flows without perturbations. Conventional interfaces were also used to install sensors to the external surface of AM parts [4].

Thanks to the knowledge about SLM [5-9], the standard process was modified in the present study by introducing special preliminary and intermediate steps (PCT/IB2019/053581) [10]. In this way, sensors and wires are protected of thermal shocks induced by laser melting of surrounding powder, and the part growth also includes the incorporation of the transducer. Different types of connectors (BNC, multi-polar, USB, etc.) can be embedded with similar approach inside the component closely to the surface, to provide external connection.

II. Samples description

The samples fabrication has the goal to calibrate the fabrication process by defining the setup parameters and operations timing, to optimize the integration of the sensor inside the material during the melting process and to support the validation of sensing performances after the process.

Two sensors typologies are considered for the optimization of the integration process, one of these has special features for high temperature exposure and even high cost, while the other one is for general use and cheaper. The first sensor type is piezo-resistive thermal sensor PT100 with cylindrical probe with 5.90 mm diameter and 30.3 mm length. The probe is connected by wire with special thermal insulation protection based on silicon. The second sensor type is general purpose piezo-resistive accelerometer with standard electric cable.

![Samples of 17-4PH parts with integration of thermal sensor (a, b) and inertial sensor (c) and 3-poles connector (d).](image)

The 17-4PH steel material is used to build the metal body of the samples, with size 90x45x20 mm\(^3\) (Fig. 1a) and 40x40x15 mm\(^3\) (Fig. 1b) for temperature and acceleration sensors, respectively. Two different configurations are provided for the sensor’s output. In the first case (Figs. 1a, ...
The output sensors curve is the same of the original sensors before the DMLS metal integration process (gain factor of 2.6 °C/Ω). The inertial sensor output is validated qualitatively.

V. Conclusions

The results synthetically exposed in this paper provides the overview of the potentialities of the technology for incorporating sensors into metal parts fabricated with DMLS processes. More generally, any kind of electronic device or circuit may be integrated similarly. At the same time, a more advanced electronic configuration of the transducer will improve the application to miniaturized and wireless components for the clinical and medical fields. In particular, the sensing of wearable systems customized on the characteristics of the individual subject is an attractive application for the near future.

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