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Sensors integration in additive DMLS metal parts

G. De Pasquale[1*], A. Buffon[1], and L. Bongiorni[1]

[1]Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy
[*] Corresponding author, email: giorgio.depasquale@polito.it

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.

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.

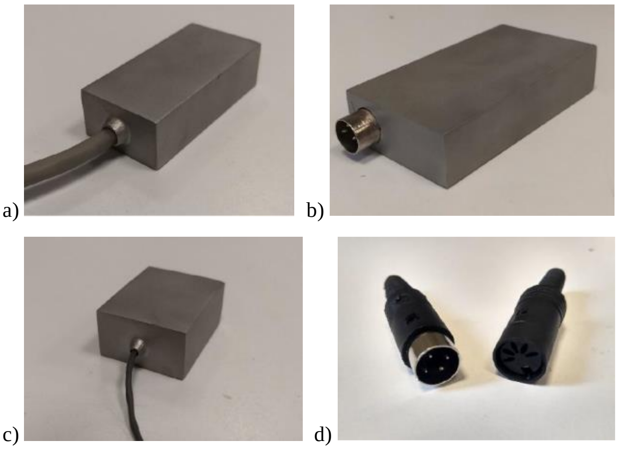

Figure 1: Samples of 17-4PH parts with integration of thermal sensor (a, b) and inertial sensor (c) and 3-poles connector (d).

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,

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1c), the cable connected to the probe or sensor directly comes outside the component. In the second case (Fig. 1b), the standard 3-poles connector of Fig. 1d is integrated into the sample through the surface. The second solution is more complicated to build and requires additional fabrication complications, but it provides more reliable cabling of external wires and prevents local cable damage at the contact with metal.

III. Micrographic analysis

The insertion of foreign bodies into the metal may induce undesired alterations in the crystallographic structure and variation of mechanical properties of the material. The SLM process optimization provided for this technology also takes care of the prevention of material alterations. The validation of material properties is based on the micrographic analysis of 17-4PH steel samples. The samples are polished, incorporated into resin and subjected to chemical treatment on the inspected side. The first surface analysis is performed with 12.5x magnification factor to evaluate the material density. Then, another analysis with 200x magnification factor provided the surface microstructure analysis. The micrographs are reported in Fig. 2.

The material density is near 100%, internal pores and discontinuities have been totally removed in the optimized process. Only a slight shift of surface layers (right border in Fig. 2a) is present, but it is easily removed with the further mechanical surface tooling. In addition, the metal microstructure is homogenous and without defects or discontinuities.

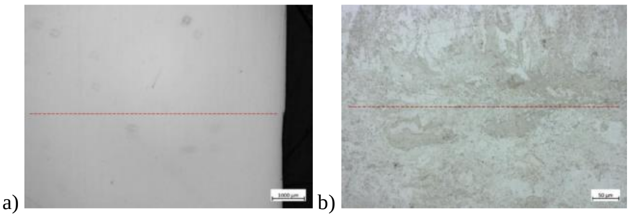

Figure 2: Surface micrographs at 12.5x (a) and 200x (b) magnification factors.

IV. Functional tests

The performances of thermal sensors are validated in terms of sensibility, repeatability and precision by functional tests after the integration process with portable analog-to-digital converter and heating plate (Fig. 3).

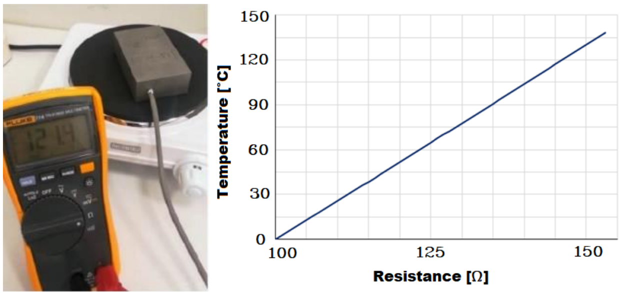

Figure 3: Functional validation of thermal sensors.

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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AUTHOR’S STATEMENT

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

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