FIAMME

Finishing processes for additive manufactured metal components

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Project description

Additive Manufacturing (AM) is a disruptive technology that has the potential to replace many conventional manufacturing processes. The adoption of AM as fabrication technique has a positive impact on the parts and assembly design, because the absence of geometric constraints allows designers focusing their efforts on part functionality. Despite its clear benefits, AM remains affected by technological issues. A characteristic of metal additive manufactured components fabricated from powder bed is the texture of the surface, originated by melting and solidification of the powder material. This mechanism leads to an average Roughness (Ra) typically higher than 20 microns, depending on the material properties and process parameters.

The main objective of the project is the study and development of a surface finishing methodology for improving the surface quality of components fabricated by additive manufacturing. Conventional and unconventional finishing processes can be applied to additive manufactured parts, but each process has a well-defined application range. For instance, processes developed for finishing internal channels are difficult to be applied to external geometries and vice versa. In the case of additive manufactured parts, due to the freedom of design and the complexity of shapes that can be realized, there is a need for the integration of existing processes to combine their specific advantages and the development of new finishing processes. These processes should be able to finish complex geometries, both external and internal, such as deep cavities and intricate through holes.

Starting from an extensive literature research on conventional and unconventional methods for surface finishing, on the basis of the characteristics of the metal alloy for AM selected as case study, a set of potential removal mechanisms and most promising media will be identified. Several copies of specimens of selected material will be produced. These samples will be outsourced to external finishing services or finished by equipment available in internal laboratories. Then, surfaces will be analysed by means of optical microscopy, SEM, and a surface profilometer.

From the inspection results it will be possible to evaluate the efficacy of each process and identify capabilities, limitations and possible improvements. Subsequently a reference part will be designed whose geometry will be representative of free-form shapes that can be fabricated by additive manufacturing. After assessing the feasibility of the reference part by the available EOSINT machine at IIT and adopted material, some copies of the artefact will be produced. These parts will be outsourced to the same finishing services or finished by equipment available in internal laboratories, for comparison purposes.

This analysis will allow to select one or more mechanisms, or a combination of them and related media for implementation of an innovative finishing process.

Team description by skill:

Enrico Degregori: studied AM principles and issue, took care of the feasibility of the final component and carried out the preliminary roughness measurements in Turin.

Eleonora Francica: dealt with the design of the first three samples and the final one (3D and CAD). She took care of the graphics and of the photo report of the experiments.

Marco Franzoso: coordinated the Turin team and exploited his Material Engineering skills in critically analyzing the problem and the solutions that were found in literature.

Matteo Loss: helped select the final AM component to produce and studied the technical features of the device to reach the desired functionality.

Pietro Magni [Communication coordinator]: coordinated the team and took care of the communications with the tutors. He also supported the design and experimental phases.

Jaspreet Singh: Performed the electropolishing and chemical polishing experiments and managed all the operations regarding sample cutting and laser profilometry.

Roberta Togati: supported the design of the final testing sample thanks to her deep knowledge of the AM process and explored its possible application as FP-OHP.

Gaia Tosti: as a designer, she followed the development of the samples and the final components in all stages. She took care of presentations, photo shooting and video making.

Abstract

The FIAMME project consisted in developing a surface finishing process that could be effective on additively manufactured (AM) components with complex geometries. AM parts can reach average roughness (R_a) values up to 100 μm, which strongly affects the possible application of the component. The team focused on the surface finishing of internal mini-channels of an oscillating heat pipe (OHP) produced through powder bed fusion techniques. The optimal roughness of the internal channels of the component was investigated thanks to data found in literature and a target value was identified. A final testing sample was designed to test the developed surface finishing procedure on more complex parts with AM-friendly features.

After an analysis of the most promising unconventional surface finishing techniques, Electrochemical finishing, Chemical finishing and Fluidized Bed machining were chosen based upon their applicability and availability. An extensive experimental study was carried out to assess their effectiveness and define their most important process parameters. Simple screening samples with different internal channel diameters,

produced using EOS's EOSINT M270 DUAL Mode machine (provided by Fondazione Istituto Italiano di Tecnologia) were used in this phase.

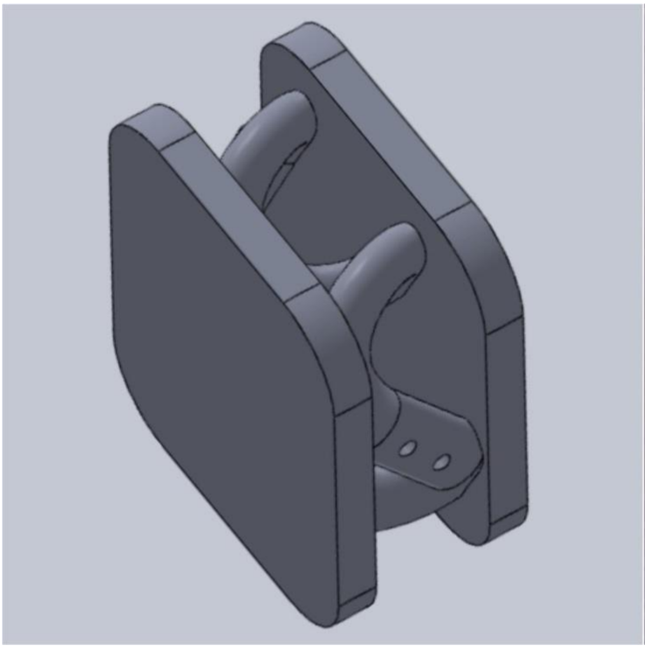
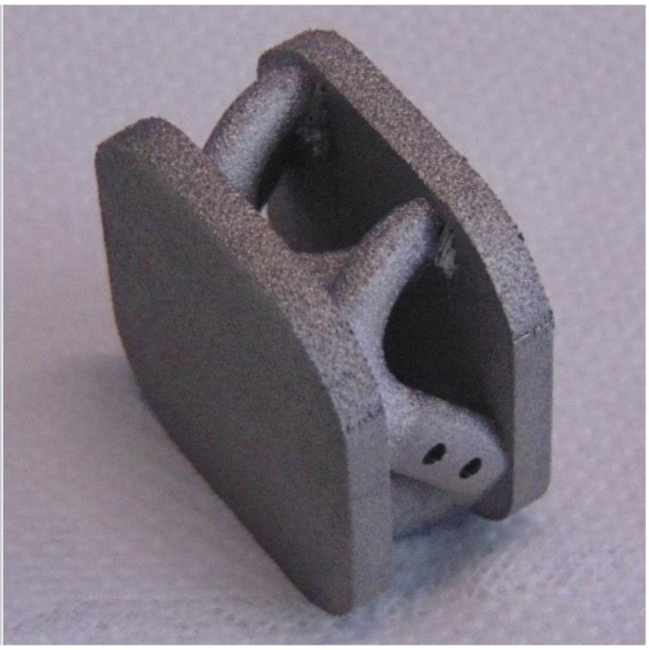
At the end of the screening process, a procedure consisting of Chemical finishing followed by Electrochemical polishing was developed and proved to be effective in reaching the target roughness value on the screening samples. The same procedure was applied on the more complex final testing sample using a peristaltic pump. However, the surface roughness value could not be measured because of a fine metallic powder that adhered to the internal channels and the result was deemed non-acceptable. Nonetheless, the procedure that was developed has significant value and needs to be further studied. It is thus believed that a simple tuning of the process parameters would allow to reach the target roughness even on more complex shapes.

UNDERSTANDING THE PROBLEM

Additive manufacturing is an exciting new production technique that allows to overcome some of the geometrical constraints typical of traditional forming processes. However, AM and, more specifically, powder bed fusion (PBF) techniques have intrinsic limits that affect the freedom of design and the properties of the final component. One of the most significant drawbacks of AM is the poor surface finishing of the parts produced, which could be incompatible with the requirements of the final application. An extensive post processing of the component may be necessary, but the complex geometry of AM components may prevent the use of conventional surface finishing techniques.

The work started with the selection of a component to analyze and improve. A previous study on a Ti-6Al-4V oscillating heat pipe (OHP) manufactured through PBF techniques was taken as a reference [1] and the effect of roughness on the functioning of this device was investigated. An OHP is a heat transfer device that effectively utilizes evaporation and condensation to transfer heat over a long distance and needs to have small internal channels to work properly. For small hydraulic passages, roughness features on the wall play a significant role in heat transfer and pressure drop characteristics of the flow. A target average roughness value of 4.59 µm was identified to balance the increase in the heat capacity (positive) and in the pressure drop (negative) of the device.

According to the team, a process of redesign of the reference OHP needed to be carried out. Even though the reference device was built taking advantage of the miniaturization that AM can provide, a traditional geometry was kept and no innovative geometrical features were implemented. What is more, the design did not consider the most significant AM geometrical constraints and problems during the manufacturing stage could be faced. For these reasons, a final testing sample (not a working prototype) was designed to illustrate how the device could be made more AM-friendly and to assess the effectiveness of the developed surface finishing procedure on typical AM channel geometries. This was a long and arduous process, during which the restrictions dictated by AM [2] and the key geometrical features of the reference component (long duct, reduced cross section) had to be carefully taken into consideration. The final testing sample consisted of two plates surrounding a spiral duct with an elliptical cross-section and two holes on the top and bottom planes to facilitate the powder removal and the surface finishing.

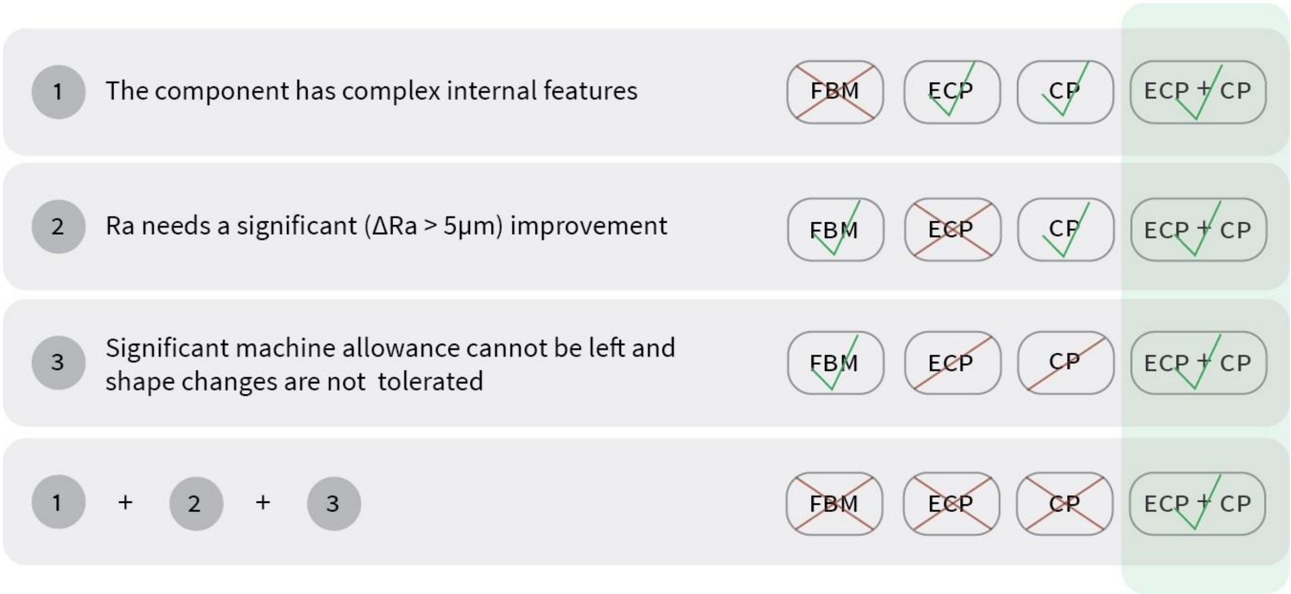



EXPLORING THE OPPORTUNITIES

Polishing small internal passages is a very challenging task, in particular for AM parts where the initial average roughness is high. Even though many unconventional surface finishing techniques have been developed and proved to be effective in polishing internal channels, there is a lack of proven solutions for AM parts [3]. A literature research was carried out to define the state of the art and multiple surface finishing processes have been analyzed, including abrasive flow finishing, fluidized bed machining, magnetic abrasive finishing, electrochemical polishing, chemical polishing and laser polishing.

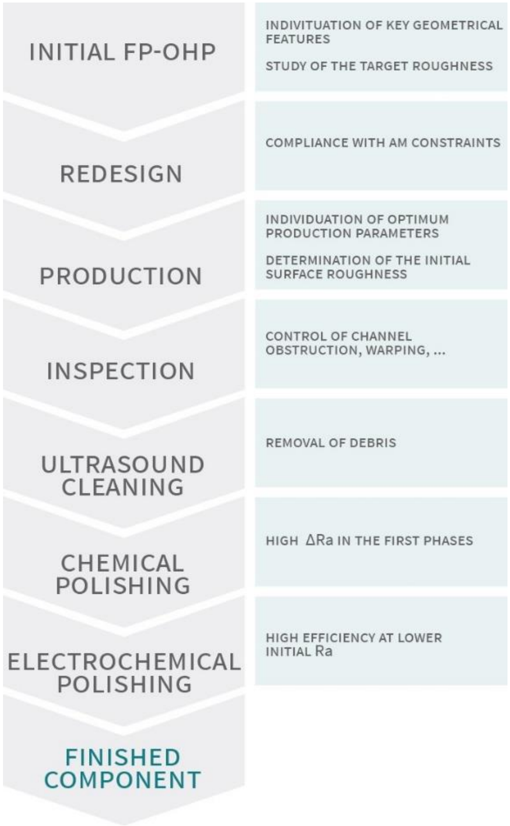
An extensive experimental work was carried out on Electrochemical finishing (ECP), Chemical finishing (CP) and Fluidized Bed machining (FBM). In this phase, screening samples with different internal channel diameters (2, 5 and 10 mm) were produced in Ti-6Al-4V using EOS's EOSINT M270 DUAL Mode machine, provided by Fondazione Istituto Italiano di Tecnologia. The three surface finishing techniques were accurately tested to assess their effectiveness and determine their optimal process parameters.

This preliminary analysis highlighted that Electrochemical polishing produces highly reflective surfaces without a sufficient improvement of the initial average roughness. Higher ΔR_a were reached using Chemical polishing but the etching rates became gradually unacceptably low as R_a diminished. Fluidized Bed machining determined significant improvement of R_a on the external surface of the screening component but the internal channels were not adequately machined.

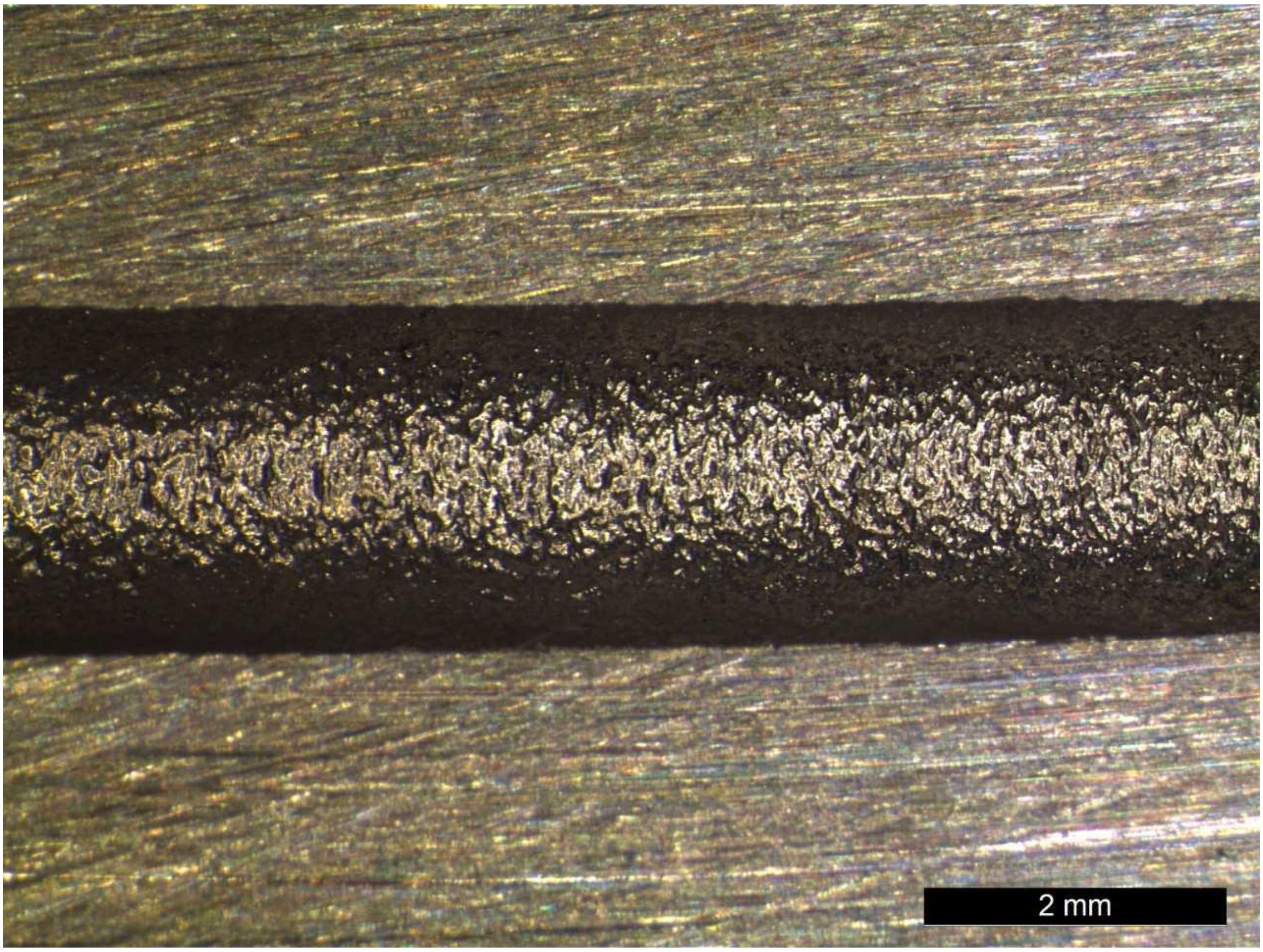


GENERATING A SOLUTION

At the end of the screening process a surface finishing procedure combining a Chemical finishing treatment and an Electrochemical polishing was developed. Following an ultrasound cleaning that removed the debris deposited on the component, a chemical polishing was carried out to smooth the rough surface finishing determined by AM and quickly achieve high ΔR_a. After that, an electrochemical polishing was applied to further reduce the roughness of the component, since it proved more effective at lower starting R_a.

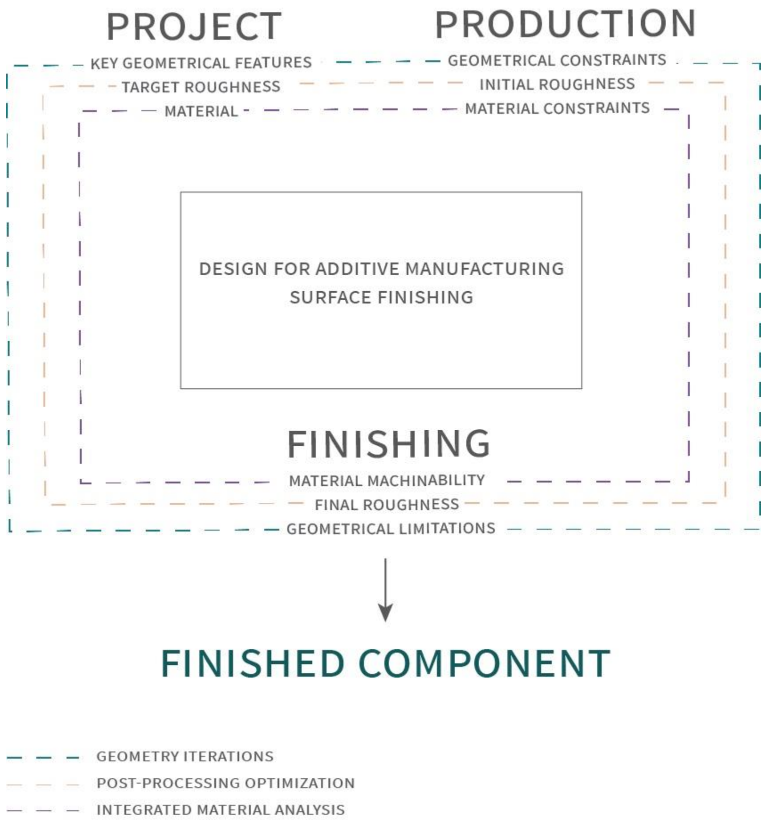


This treatment was preliminarily tested on the screening samples and allowed to reach the target roughness value. A smooth and reflective surface was obtained in the internal channels of the screening samples and the final roughness value could be controlled as a function of the process parameters of the two surface finishing techniques that were coupled. This procedure did not require any complex apparatus and the process parameters could be easily tuned to obtain different values of the final surface roughness.



This procedure was then extended to the final testing sample with the more complex channel geometry. Given the longer ducts of this component, a peristaltic pump had to be used to have the etching Chemical finishing solution and the Electrochemical polishing electrolyte solution flow into the channels and remove the metal alloy debris. However, the combined treatment determined the formation of a fine powder strongly adhered to the surface of the internal channels. This deposit did not allow to measure the surface parameters of the sample, but the morphology observed was deemed non-acceptable. Nonetheless, it is believed that an appropriate tuning of the process parameters (including that of the peristaltic pump) could extend the efficacy of this treatment even to more complex ducts.

The added value of the project lies in the study and implementation of a method for surface finishing of parts produced through AM with complex shape features. This procedure is the result of the combination of different surface finishing techniques whose operating parameters have been fine-tuned to achieve the target roughness. While the performance of the procedure is – of course – impacted by the geometry of the part, it is extremely flexible and can be applied to a vast range of shapes and sizes by varying the operating parameters. The working method that was followed could be easily extended to the surface finishing of other AM components and unconventional geometries in general. It is clear from the research carried out that the design, production and finishing of the part influence one another and a multidisciplinary approach should be followed to reach optimum results.



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TAGS

Additive; Manufacturing; Finishing; Polishing