Joint Special Interest Group meeting between euspen and ASPE
Dimensional Accuracy and Surface Finish in Additive Manufacturing,
KU Leuven, BE, October 2017
www.euspen.eu

# Finishing of internal and external surfaces produced by Powder Bed Fusion

M.Hamidi[1], A.Falzetti[1], A.Redaelli[1], N.Lecis[1], A.Giussani[2], L.Sala[2], M.Vedani[1]

[1]*Department of Mechanical Engineering, Politecnico di Milano, Italy*
[2]*Rösler Italiana S.r.l, Italy*

*Milad.hamidi@polimi.it*

**Abstract**

The objective of this study is to propose and evaluate various surface finishing techniques aimed at reducing the external and internal surface roughness of AM parts. In the tool and die sectors, integration of conformal cooling channels by Additive Manufacturing (AM) is of great interest. For the investigation, samples were specifically designed with different channel geometries and diameters and printed in Maraging Steel (Grade 300) by Powder Bed Fusion (PBF). Three different techniques for surface post-treatment were investigated including: Vibro-finishing, sandblasting followed by vibro-finishing and chemically assisted vibro-finishing. Microscopy analyses and profilometry were adopted to understand the effects and phenomena regarding to each process.

Keywords: additive manufacturing; powder bed fusion; conformal cooling; surface roughness, Maraging steel

## 1. Introduction

Additive Manufacturing (AM) allows the manufacturing of part geometries that are technically infeasible through the conventional manufacturing techniques. Therefore, it represents an outstanding opportunity in the production of structural complex parts with integrated functions such as conformal cooling systems, etc. which make them attractive for the tooling industry, hydraulics and aerospace sectors [1]. The PBF printed parts typically suffer from high surface roughness in the as built condition compared to conventionally machined parts. The *Ra* value of these surfaces is around 10 µm to 20 µm which is due to the particulate contamination originated during the printing process by partially unmelted particles stuck to the surface and the creation of splatters caused by the interaction between high energy laser beam and the melt pool [2-3]. The surface roughness of the printed parts varies depending on the process parameters [4], processed materials [5], particle size and distribution [6] and AM method [7].

In particular, for the internal surfaces of additively manufactured parts new and effective post treatment methodology is strongly required since conventional machining and standard surface-finishing procedures are not able to reach the internal surfaces in complex parts. Excessive surface roughness of the internal channels can cause head losses and turbulence [8-9]. Accidental detachment of stocked particles can also induce fluid contamination or system failure. In addition, high surface roughness is not desirable, since debris might be released from the surface and might inflict damage to other equipment. Accordingly, the correct surface conditioning is important for the component's life and the efficiency of the system [10].

The present research focuses on different post-processing techniques in order to achieve the desirable surface quality inside channels of dies produced by AM. Therefore, samples integrating channels with different shapes and sizes have been designed and printed in Maraging steel to simulate the hydraulics and conformal cooling systems. Three different approaches for post-processing were adopted including: vibro-finishing (VF), sandblasting accompanied by vibro-finishing (SB + VF) and chemically assisted (CA) vibro-finishing. The evolution of the surface quality has been investigated during each process by microscopy analysis and profilometry.

## 2. Materials and Methods

Components integrating L-type and U-type channels in diameter varieties of (3, 5, 7.5 and 10 mm) were designed to simulate hydraulics and conformal cooling channels (Figure 1). Four identical samples were printed by a Renishaw AM250 system in Maraging steel type 300 to evaluate the above mentioned post-processing techniques.

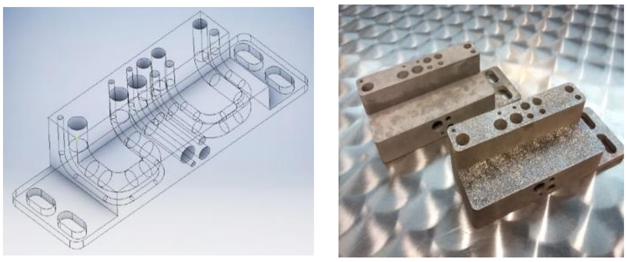

**Figure 1.** CAD image and real views of the printed samples (left and right, respectively).

VF is the process of parts being submerged in media and compounds (specially treated water) within a vibratory finishing machine. The machine vibrates causing the work pieces to move in a circular motion and the media to grind against the parts, to get the desired surface aspect and roughness [11].

In case of SB + VF, a slight sandblasting with white corundum ($Al_2O_3$) under 4 bar of pressure was performed prior to the vibro-finishing stage in order to initially decrease the roughness by breaking the largest asperities.

In case of CAVF, the VF process was chemically enhanced by using a solution primarily composed by oxalic acid, sodium nitrobenzenesulfonate, boric acid and hydrofluoric acid. The particularity of oxalic acid is the ability to create a thin brittle and spongy layer of conversion coating in contact we Fe alloys. The cyclic formation and removal of this layer is caused by the continuous presence of media impacts following by the continuous conversion layer formation. This layer being thick few nanometres, follows perfectly the surface topography. The asperities on the surface of the part that are more frequently exposed to the impacts are gradually reduced while the cavities are less affected, consequently the surface is progressively smoothed out.

The described processes were carried out in the following steps: the sample was mounted in the centre of the Domeless machine and covered with the corresponding media, then a continuous water flow through appropriate dispensers and necessary additives such as corrosion inhibitors and soap were applied. For the sake of comparison, machine parameters (speed, rotation direction, sample positioning and orientation, water flow and etc.) were kept the same for all the tests. Once the cycle was completed, the samples were removed and a simple cleaning from process residues was done following with roughness analysis employing a stylus profilometer. Every analysis was performed taking 5 measurements with a length of 5.6 mm each deploying a standard Gaussian filter and then the final value was calculated as the average of the parameters obtained on each measure with the corresponding standard deviation. The composition of the abrasive media and acid solution for each process is presented in Table 1.

| Process | Media Composition | No. of VF cycles | Total time (h) |
|---|---|---|---|
| VF | ***High density Porcelain, boron carbide*** | 4 | 64 |
| SB + VF | ***High density Porcelain, boron carbide*** | 3 | 48 |
| CAVF | ***Oxalic Acid, Sodium Nitrobenzenesulfonate, Boric Acid*** and ***Hydrofluoric Acid*** | 2 | 32 |

**Table 1.** Abrasive media composition and processing condition of the investigated samples

The inner channels were then sectioned employing a diamond blade in order to characterize their interior surfaces. Microscopy analyses were performed by utilizing an optical microscope (OM), a stereo microscope (SM) and a scanning electron microscope (SEM).

### 3. Results and Discussion

In this section, for sake of comparison, only the results from L-shaped channels with 10 mm diameter are presented. In Figure 2, SEM cross-sectional views of the inner channel surfaces of the as-manufactured part are presented. The difference between top view and bottom view of the horizontal channel is due to the laser tracks which exist only on the bottom area of the horizontal channel resulting in different roughness values in different positions inside the corresponding channel. The spatter effects accompanied by the partially melted powders resulting from the print process and the laser scanning directions are clearly visible.

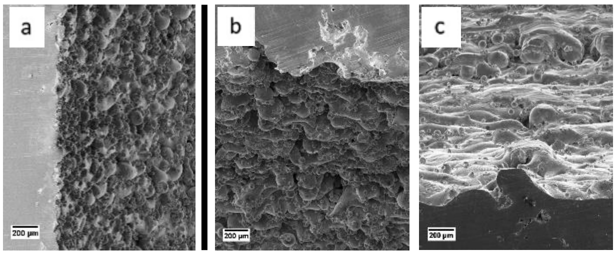


**Figure 2.** Cross-sectional view of as-built sample: (a) vertical channel, (b) horizontal channel (top view), (c) horizontal channel (bottom view).

To better understand the difference in these processes, SEM images supported by the roughness profile after each process is presented in figure 3. Here it is to notice the similarity between VF and SB + VF as in both cases spatter effect has been mostly removed and a similar roughness profile was achieved. CAVF showed the smoothest surface and the best results according to its roughness profile and SEM morphology. It is shown that the method allows to achieve the lowest *Ra* value of 0.7 µm.

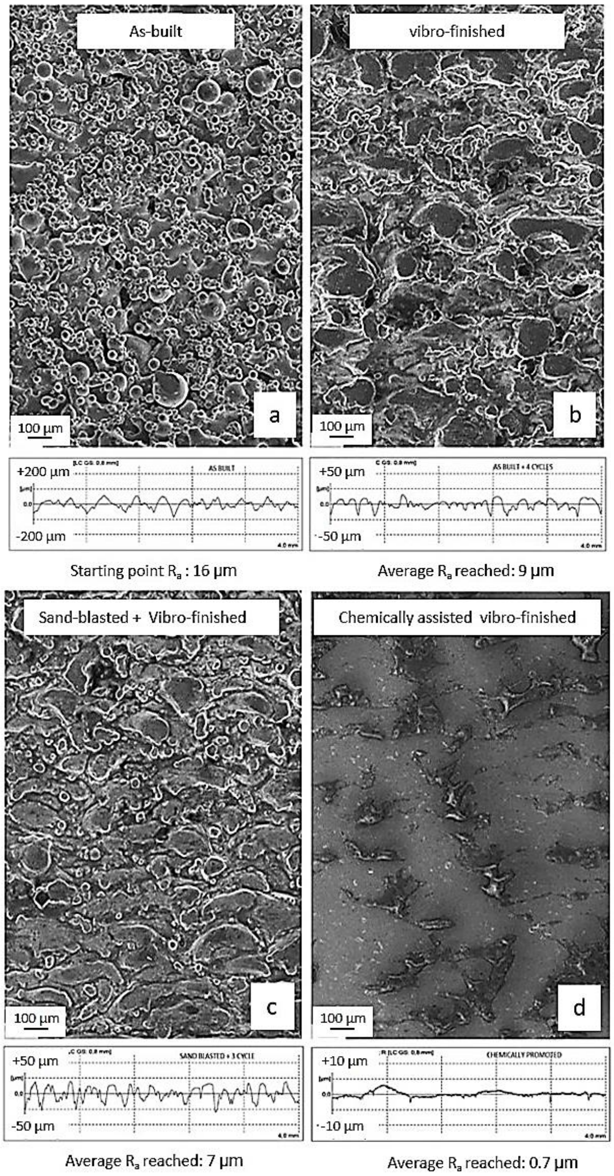


**Figure 3.** Surface morphology of the channels and their corresponding roughness profiles: (a) as-built, (b) VF, (c) SB+VF, (d) CAVF.

The evolution of *Ra* values for the vibro-finishing processes in the vertical and horizontal channels are given in the Figure 4. As-built horizontal channels feature higher roughness than vertical channels; preliminary sandblasting reduces the roughness approximately to the same extent for both orientations. It is also shown that the final roughness values in the vertical and horizontal channels are very similar to each other. The sandblasting allows to reduce almost one cycle of the processing, leading to the same final roughness value. The best process is the chemically assisted vibro-finishing, which reached the lowest roughness values in the shortest time.

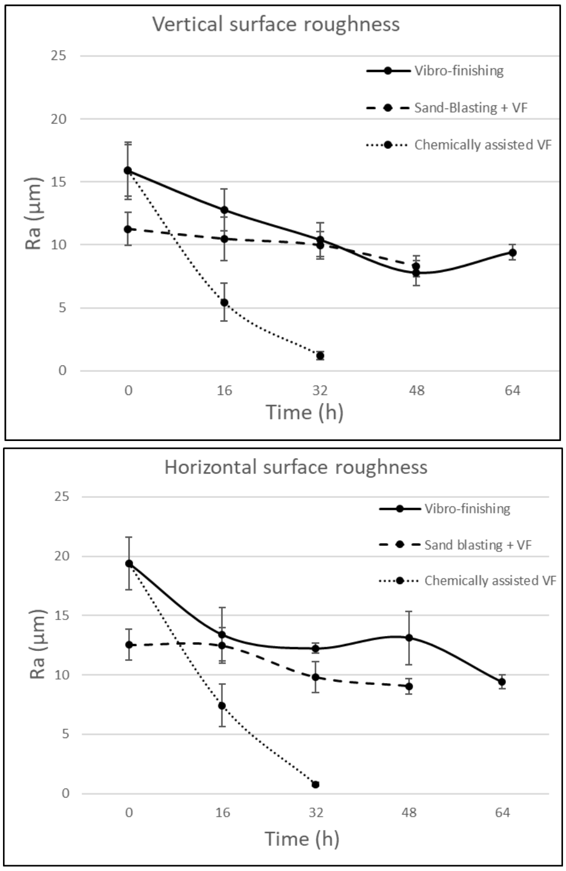


**Figure 4.** *Ra* evolution during different vibro-finishing processes for vertical (top) and horizontal (bottom) channels.

## 4. Conclusion

The effectiveness of the vibro-finishing for the reduction of roughness on the internal channel surfaces of printed samples has been investigated. Analyses showed that the treated surfaces were free from spatters and loose powders. The most effective choice amongst performed methods is chemically assisted vibro-finishing, allowing to reach roughness values as low as 1 µm.

### References

[1] F. Abe, K. Osakada, M. Shiomi, K. Uematsu, and M. Matsumoto, “The manufacturing of hard tools from metallic powders by selective laser melting,” *J. Mater. Process. Technol.*, vol. **111**, no. 1, pp. 210–213, 2001.

[2] N. Nutal *et al.*, “Surface engineering for parts made by additive manufacturing,” in *IAC-15, the 66th International Astronautical Congress*, 2015, p. C2.

[3] A. Townsend, N. Senin, L. Blunt, R. K. Leach, and J. S. Taylor, “Surface texture metrology for metal additive manufacturing: a review,” *Precision Engineering*, vol. **46**. pp. 34–47, 2016.

[4] J. P. Kruth, L. Froyen, J. Van Vaerenbergh, P. Mercelis, M. Rombouts, and B. Lauwers, “Selective laser melting of iron-based powder,” *J. Mater. Process. Technol.*, vol. **149**, no. 1, pp. 616–622, 2004.

[5] C. Y. Yap *et al.*, “Review of selective laser melting: Materials and applications,” *Appl. Phys. Rev.*, vol. **2**, no. 4, 2015.

[6] A. B. Spierings, N. Herres, and G. Levy, “Influence of the particle size distribution on surface quality and mechanical properties in AM steel parts,” *Rapid Prototyp. J.*, vol. **17**, no. 3, pp. 195–202, 2011.

[7] W. E. Frazier, “Metal additive manufacturing: A review,” *J. Mater. Eng. Perform.*, vol. **23**, no. 6, 2014.

[8] J. Pakkanen *et al.*, “Study of Internal Channel Surface Roughnesses Manufactured by Selective Laser Melting in Aluminum and Titanium Alloys,” *Metal. Mater. Trans. A Phys. Metall. Mater. Sci.*, 2016.

[9] C. Semini *et al.*, “Additive manufacturing for agile legged robots with hydraulic actuation,” in *Proceedings of the 17th International Conference on Advanced Robotics, ICAR 2015*, 2015, pp. 123–129.

[10] L. W. MAYS, *Hydraulic design Handbook*. New York: McGraw-Hill, 1999.

[11] F. Hashimoto and S. P. Johnson, “Modeling of vibratory finishing machines,” *CIRP Ann. - Manuf. Technol.*, vol. **64**, no. 1, pp. 345–348, 2015.