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Exploring The Impact Of Cost-Effective Surface Treatments On The Roughness and Geometry Of FFF Sintered Parts

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Abstract

Many requirements and applications in various industrial sectors demand high-quality finishes on parts. These finishes, whether due to tolerances or surface quality, are often challenging to achieve through additive manufacturing technologies, necessitating additional post-processing. This study aims to investigate the effect of specific surface treatments on parts produced through Sintering Based Additive Manufacturing (SBAM), such as Fused Filament Fabrication (FFF). With the premise of employing affordable post-processing methods that can potentially maintain competitive prices for the parts, the study analyzes the post-processing techniques of shot blasting and vibratory polishing on parts with different geometries. Additionally, the study examines the effect of surface treatments on part walls manufactured at various angles. The results obtained demonstrate significant improvements in surface roughness, although there is potential for them to modify the geometry and round the edges of the parts.

Keywords: SBAM, metal FFF, surface finish, post processing

Introduction

Additive manufacturing based on sintering using Fused Filament Fabrication (FFF) technology is emerging as an interesting method for prototyping and producing short to medium lots of metal part, with several studies for different applications and materials[1]–[3]. One of the main advantages is the use of raw materials compatible with the MIM process chain.

Despite the considerable improvement in the resolution and quality of the parts that can be obtained [4], the surface finish may still be a limiting factor for certain applications. This is mainly due to the staircase effect, which is more pronounced compared to other metal additive manufacturing technologies such as LPBF or BJ.

Despite there are some literature works related to the finishing process of FFF polymeric parts [5], [6], there is still a lack of literature information about the surface finishing of metal FFF parts. To this aim, the present study aims to seed some light in the postprocessing of FFF parts with easy to use and affordable processing techniques, which can be easily implemented and do not require a high level of technical qualification.

Materials and methods

In this study, the influence of affordable surface treatments such as shot blasting and vibratory polishing on metal FFF parts is have been analysed. Filament from BASF with 17-4PH metal powder and catalytic debinding binder was used, and the test specimens shown in Figure 1 were printed in an Ultimaker S5 3D printing machine. Each type of piece has been used to analyse how the post-processes affect different geometric characteristics, examining surface roughness on walls with different inclinations, the penetration of treatments into cavities, and their effect on thin walls.

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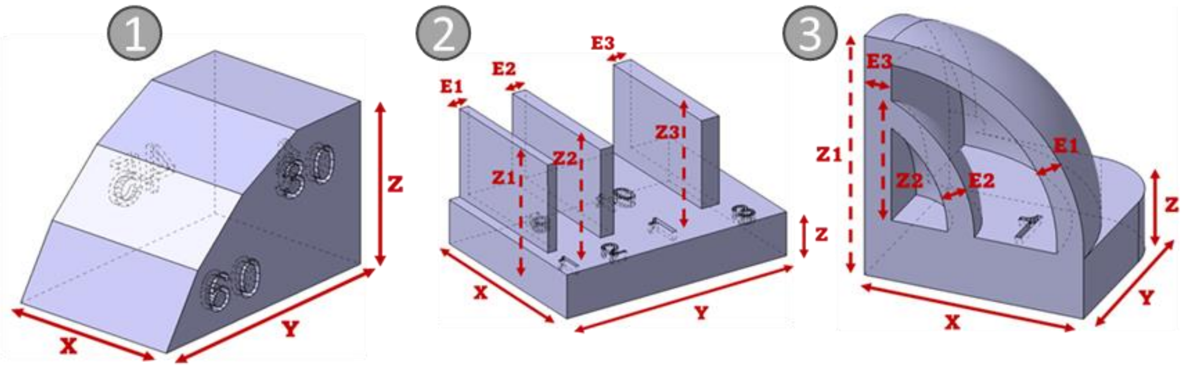

Part	X	Y	Z	Z1	Z2	Z3	E1	E2	E3
1	20	30.73	20.73						
2	20	25	5	15	15	15	1	1.5	2
3	16.3	14.3	5	20	10		2	2	2

Figure 1. Printed sample geometries and their dimensions in mm

For the study of shot blasting, the parts were shot blasted in the green state and after sintering. Different types of shot media, such as fine F220 corundum (F), coarse F36 corundum (C), and metallic blasting media (M), were tested. The shot blasting was carried out at a pressure of 2 bar, keeping the gun 20 cm away from the parts and projecting for no more than 30 seconds per side.

On the other hand, the study of vibratory polishing (P) was carried out directly on sintered parts, some of which had also been previously shot blasted to examine the effect of both processes. For this treatment, 5mm conical abrasive media were used, and parts were polished for 4, 6 and 8 hours.

The parts were dimensionally characterized before and after each treatment at the points indicated in Figure 1. This characterization was carried out using a digital calliper and an Olympus DSX10D digital microscope. The surface roughness was measured with a contact needle profilometer.

Results and discussion

Figure 2 shows the visual appearance of some samples with different blasting treatments. The image on the left represents the part after printing, centered on a corner and a wall inclined at 30 degrees, where the staircase effect of the FFF process is clearly observed. The use of fine corundum shot does not seem to affect the part much, while the combinations of coarse and fine corundum, and the metallic shot, appear to eliminate the staircase effect. Of these two, the metallic shot seems to round off the sharp edges of the part less.

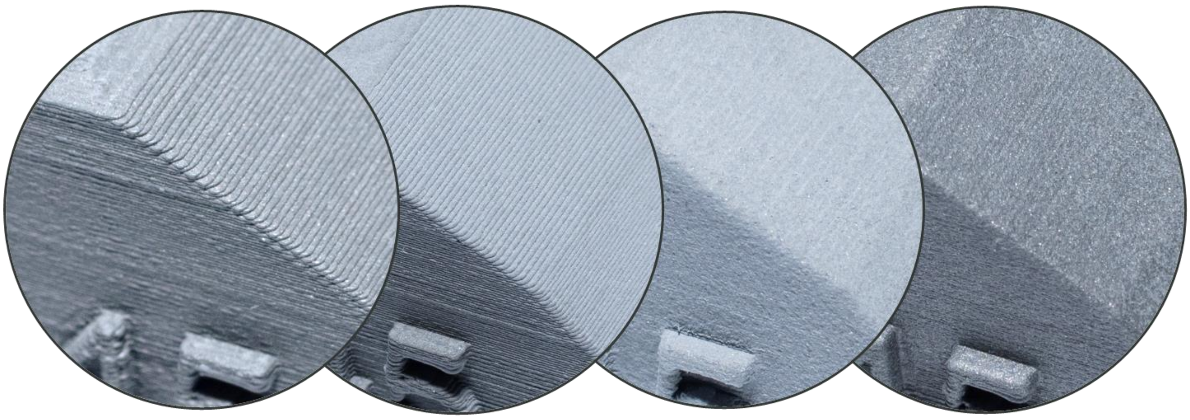

Figure 2. Green samples in different states (from left to right): as-printed, fine corundum blasted, coarse+fine corundum blasted, and metallic ball blasted

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Additionally, it is worth mentioning a potential adverse effect of this type of process. Using ceramic blasting media with sharp edges and a particle size similar to possible engravings or grooves on the part can lead to incrustations that may be difficult to remove afterwards, as shown in Figure 3.

Figure 3. Blasting media incrusted into a part engraving

Furthermore, the penetration of the treatment into certain cavities may be limited. As observed in Figure 4, the polishing or removal of the staircase effect does not occur over the entire internal surface. This is due to the turbulence and currents generated inside, which prevent the blasting media from impacting the walls of the part.

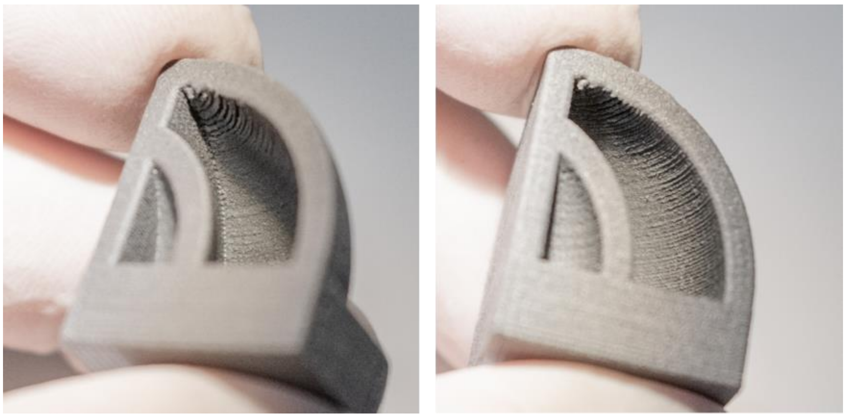

Figure 4. Effect of blasting in the inner surfaces of a FFF sample

Figure 5 shows the results of roughness measurements on the green parts as a function of the wall inclination where they were measured, and as a function of the different shot media used. As can be observed, the use of fine or coarse corundum shot alone slightly reduces the roughness of the part, but there is still a significant difference in roughness between walls of different inclinations. In contrast, the metallic shot or combination of the two corundum shots significantly reduces roughness and homogenizes it, making it independent of the wall inclination.

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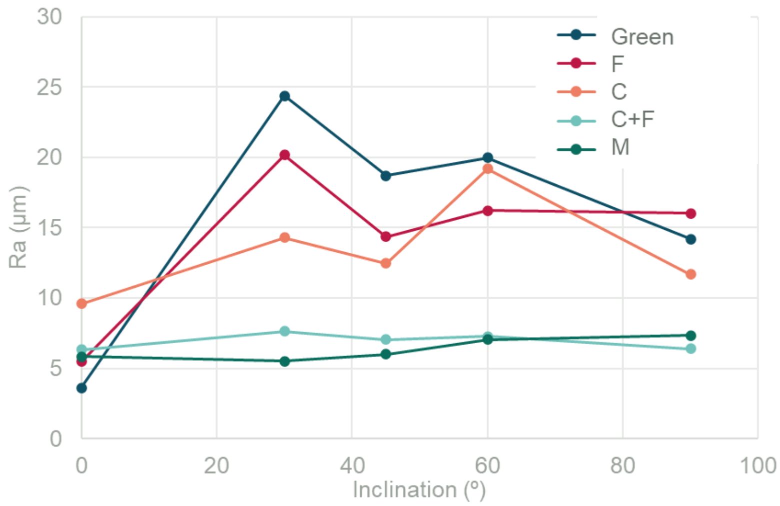

Figure 5. Surface roughness in green state in function of part wall inclination and the blasting media

Among all the methods, metallic shot blasting seems to emerge as the best alternative, as it allows to achieve the greatest reduction in roughness using only one type of shot media, and no incrustations are observed in the engravings of the parts. The parts shot blasted in the green state have been sintered, and the roughness has been analyzed again to see if it changed. The results shown in Figure 6 demonstrate that the roughness after sintering is directly comparable to that of the green part. This means that, if quality control is necessary, the roughness could be measured directly on the green part, avoiding the sintering of defective parts and saving manufacturing costs.

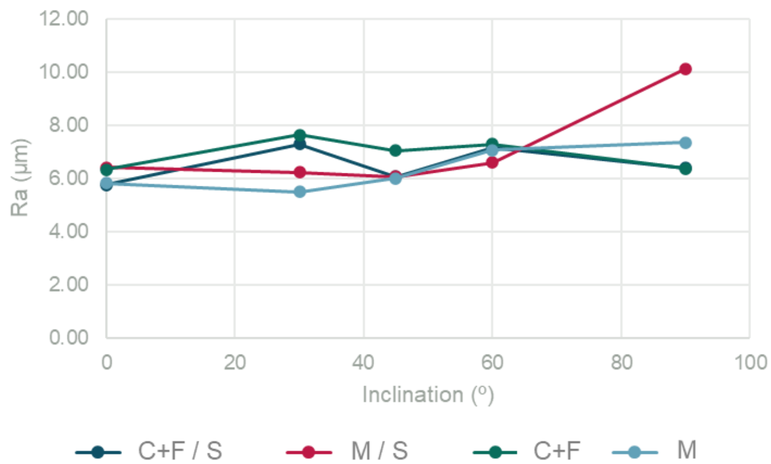

Figure 6. Surface roughness in function of wall inclination and blasting media, for green parts before and after sintering

After analyzing the roughness of the parts treated in the green state, the roughness of parts treated before and after sintering was also analyzed. For this case, the parts with the best results were shot blasted again, using the best shot media: metallic and a combination of coarse and fine corundum. As can be seen in Figure 7, metallic shot blasting before and after sintering slightly reduces the roughness compared to the part shot blasted only in the green state, yielding the best roughness result obtained so far.

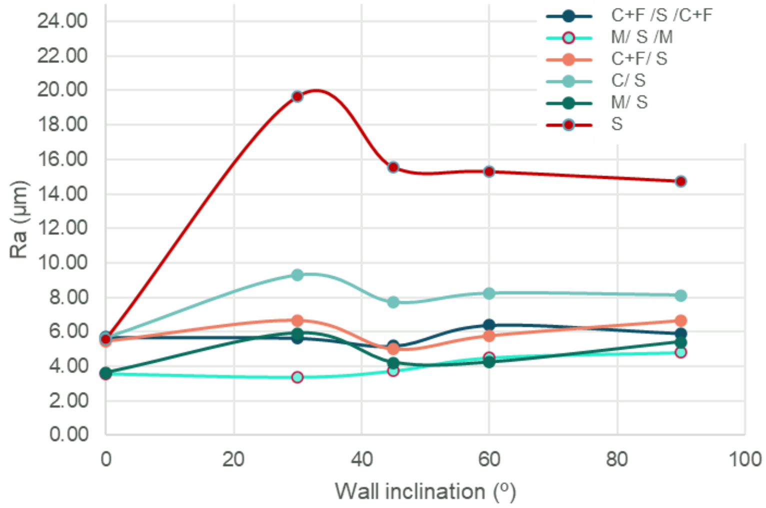

Figure 7. Surface roughness in function of the wall inclination and different blasting media used before and after sintering

Additionally, Table 1 presents the roughness data measured on walls of different inclinations for an FFF part that was only sintered, without any treatment, compared to a part that was shot blasted before and after sintering with metallic shot. As can be observed, the average roughness decreases by an order of magnitude compared to the original part. Furthermore, the standard deviation decreases notably, indicating a homogenization of the roughness across all faces of the part, regardless of wall inclination.

Wall inclination (º)	0	30	45	60	90	Average Ra (µm)	Desvest (µm)
S	5.58	19.68	15.54	15.29	14.73	**14.16**	**5.18**
M/ S /M	3.56	3.35	3.73	4.50	4.81	**3.99**	**0.63**

Table 1: Surface roughness for FFF as sintered part and FFF part blasted before and after sintering with metallic blasting media

For vibratory polishing, as mentioned earlier, 3 different polishing times have been tested 4h, 6h, and 8h. For the study, sandblasted parts with metallic blasting media after sintering, as well as parts sandblasted before and after sintering, and parts without any prior process have also been studied. Table 2 shows the Ra values obtained after treatment for the different combinations of parts and polishing times. As can be observed, the roughness partially decreases with the increase in polishing time, but there is no significant improvement in increasing from 6h to 8h. On the other hand, the roughness values obtained for parts only polished by vibration are higher than the parts sandblasted before and after sintering. The substantial improvement in roughness is seen for the polished parts that have been previously sandblasted before and after sintering, obtaining values close to 2µm of Ra.

Testing time	Average (µm Ra)	Desvest (µm)
4	5.57	3.1
6	4.22	2.35
8	4.54	1.95
SM4	3.26	1.1
SM6	3.5	1.18
SM8	2.51	0.54
MSM4	2.35	0.31
MSM6	2.47	0.74
MSM8	2.34	0.88

Table 2: Surface roughness values for different vibration polishing times and different kind of parts previously blasted

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On the other hand, it is worth noting that these polishing processes cause certain dimensional variations and distort some geometric elements of the part. Therefore, as a clear indicator of the effect of these processes, the curvature of sharp 90º corners and their evolution due to the treatments has been measured. Figure 8 shows an image and the measurements taken on a part after vibratory polishing, captured with the digital microscope. Figure 9 presents the values of these curvatures measured on parts before the shot blasting and polishing treatments, as well as for the different tested combinations, also depending on the vibratory polishing time.

As it can be observed, the combination of metallic shot blasting before and after sintering, followed by vibratory polishing, results in the most rounded edges. On the other hand, it is notable that there is no observed trend of increasing curvature radius with longer polishing times. This indicates that the rounding of edges or sharp corners due to polishing occurs initially with a short treatment time, and that increasing the treatment time does not significantly increase this curvature. However, it does slightly improve the roughness.

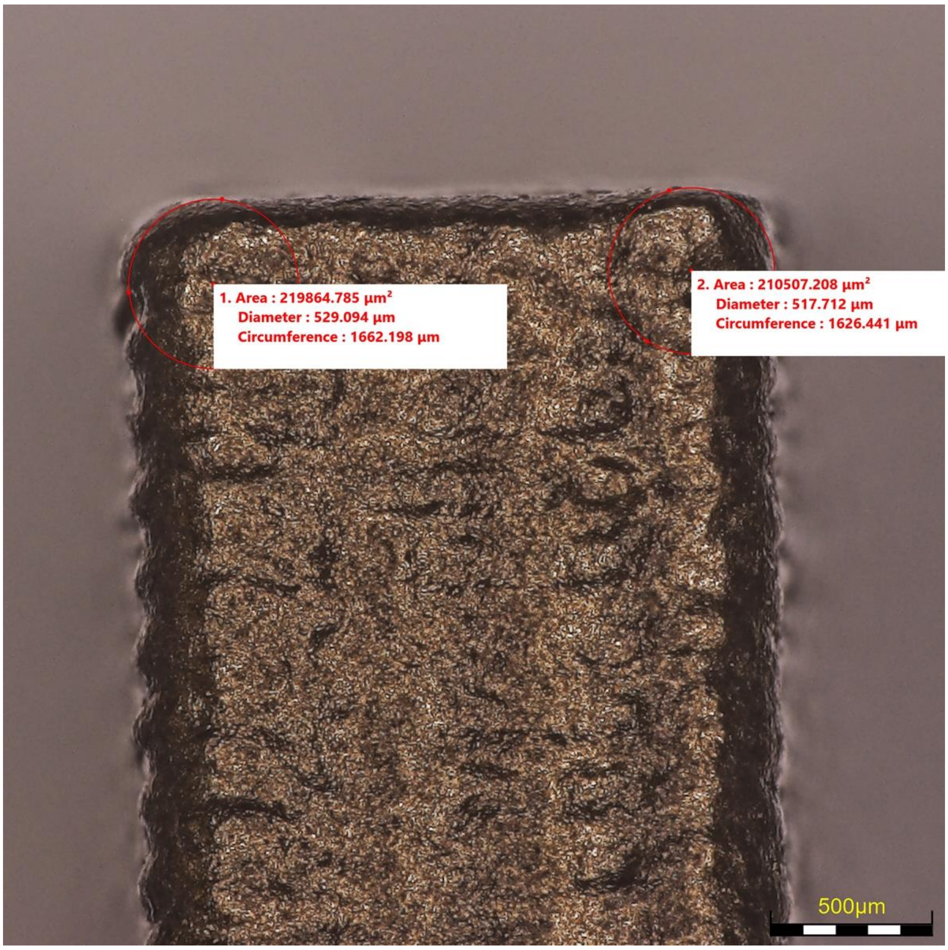

Figure 8. Edge curvature measurement of a vibratory polished part with digital magnification glass

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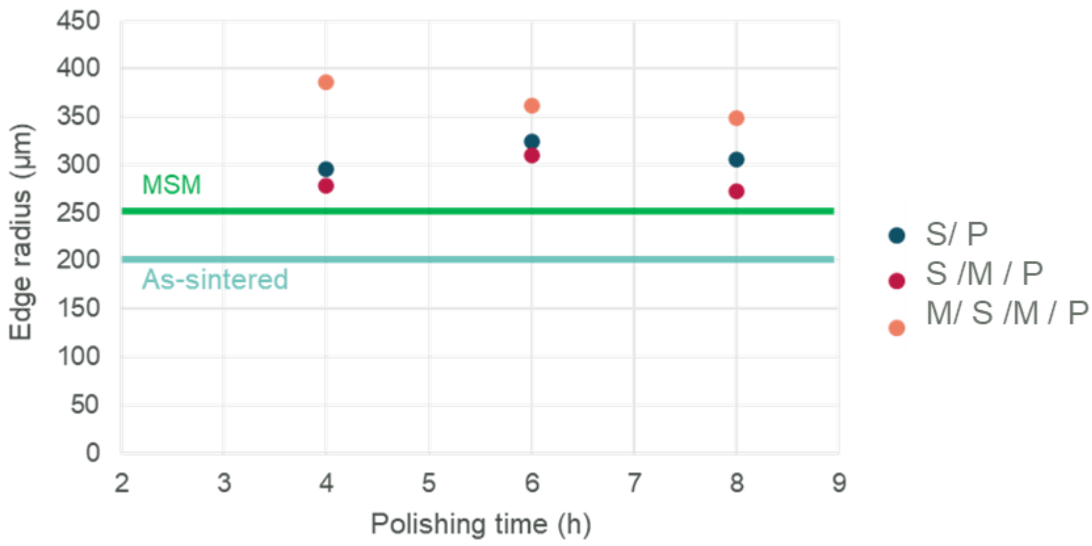

Figure 9. 90º sharp edge radius after the surface treatments

Conclusions

This study demonstrates that shot blasting and vibratory polishing are effective surface treatments for improving the quality of metal FFF parts. Shot blasting, particularly with metallic media, significantly reduces surface roughness and eliminates the staircase effect seen in the printed parts. Among the different shot media tested, metallic shot emerges as the most effective, achieving substantial roughness reduction and preventing incrustations. Additionally, roughness measurements on green parts are indicative of post-sintering results, suggesting that quality control can be effectively conducted before sintering, thereby saving manufacturing costs. Vibratory polishing further enhances surface finish, especially when combined with pre- and post-sintering shot blasting. However, it also introduces dimensional changes and rounds sharp edges, with the most significant effects occurring early in the treatment. Overall, the combination of metallic shot blasting followed by vibratory polishing yields the best surface finish and roughness results, though care must be taken to account for any dimensional alterations.

Acknowledgements

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References

[1] J. E. Montes-Ramirez *et al.*, “Shrinkage and deformation compensation in metal fused filament fabrication (mf3) sintered copper components using 3d scanning and inverse deformation,” *J. Manuf. Process.*, vol. 121, pp. 9–19, Jul. 2024, doi: 10.1016/J.JMAPRO.2024.04.069.

[2] D. Nötzel, R. Eickhoff, and T. Hanemann, “Fused Filament Fabrication of Small Ceramic Components.,” *Mater. (Basel, Switzerland)*, vol. 11, no. 8, Aug. 2018, doi: 10.3390/ma11081463.

[3] C. Tosto, F. Miani, and G. Cicala, “The Impact of Fused Filament Fabrication (FFF) Printing Profiles on 17-4 PH Green and Sintered Parts,” *Macromol. Symp.*, vol. 411, no. 1, p. 2200133, Oct. 2023, doi: 10.1002/MASY.202200133.

[4] M. Kain, P. Parenti, M. Annoni, M. Calaon, D. B. Pedersen, and G. Tosello, “Performance evaluation of polymer-filled metal fused filament fabrication tooling for profile extrusion,” *Int. J. Adv. Manuf. Technol.*, pp. 3363–3378, 2024, doi: 10.1007/s00170-024-13475-1.

[5] A. Chueca de Bruijn, G. Gómez-Gras, and M. A. Pérez, “On the effect upon the surface finish and mechanical performance of ball burnishing process on fused filament fabricated parts,” *Addit. Manuf.*, vol. 46, p. 102133, Oct. 2021, doi: 10.1016/J.ADDMA.2021.102133.

[6] I. Gajdoš, E. Spišák, Ľ. Kaščák, and V. Krasinskyi, “Surface Finish Techniques for FDM Parts,” *Mater. Sci. Forum*, vol. 818, pp. 45–48, 2015, doi: 10.4028/WWW.SCIENTIFIC.NET/MSF.818.45.