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Finishing of metal additive manufactured parts by abrasive fluidized bed machining

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Abstract
A characteristic of metal additive manufactured (AM) components fabricated by Laser Powder Bed Fusion process (L-PBF) is the texture of the surface, primarily originated by melting and solidification of the powder material. This mechanism leads to an average surface roughness of 8-25 µm, depending on the material properties and process parameters. In some applications, AM parts require a surface smoothing process to meet part specifications. Conventional finishing processes may not be appropriate to finish the complex geometries that are typical of AM products, such as deep cavities and intricate through holes. Abrasive fluidized bed (AFB) machining is a recent finishing process developed at the University of Rome Tor Vergata that employs an abrasive fluidized bed to improve surface finish by material erosion. This work aims to explore the capability of the AFB method as finishing method for AM products. Thus, a specimen with curved surfaces and internal holes was designed and several copies were produced by L-PBF process. The samples were then subjected to the AFB surface finishing treatment. The influence of the operational parameters on the finishing performance was investigated. The achievable surface roughness and the deviations of the part geometry induced by the finishing process were identified by dimensional and surface inspection. From the inspection results, it was possible to assess the effectiveness of the process and to identify capabilities, limitations and possible improvements.

Additive Manufacturing, Selective Laser Melting, Titanium Ti64, Fluidized bed, Finishing

1. Introduction

Additive Manufacturing is a pillar of the Industry 4.0. This technology allows engineers to design very complex components which are impossible to fabricate with other systems. In other words, from the 3D CAD model, it is possible to directly produce added-value geometries, in a large variety of materials with competitive costs and times.

Generally, for metal parts, the leading processes are L-PBF (Laser Powder Bed Fusion) and EB-PBF (Electron Beam Powder Bed Fusion). Especially, L-PBF offers a good balance between part quality, costs and materials. Despite its clear benefits, L-PBF remains affected by some technological issues. Average value of surface roughness (R_a) of L-PBF parts is 8-25 µm [1, 2] and might not comply with the stringent requirement of mechanical applications. In fact, L-PBF parts often require a finishing process to improve surface quality. Both unconventional finishing systems, such as laser ablation, chemical or electrochemical processes, and traditional systems, such as abrasive machining, may be applied to additive parts. Among them, Abrasive Fluidized Bed (AFB) machining is a good trade-off among low cost, short processing time and system easiness. The feasibility of using the AFB method to finish flat external surfaces of AlSi10Mg L-PBF products has already been demonstrated [3]. In this work, a specimen with geometry including classical and measurable features that resemble AM geometries is produced by L-PBF and tested by AFB. The AFB apparatus is equipped with an epicycloidal gearing mechanism, in order to apply a rotating motion to the piece and to expose to the abrasive bed all the surfaces of the specimen. The achievable surface roughness and the deviations of the part geometry induced by the finishing process are identified by dimensional and surface inspection. This experimental study is carried out to assess the effectiveness of the AFB process in the finishing of curved surfaces and internal channels and define its most important process parameters.

2. Abrasive Fluized Bed (AFB) finishing

A specimen with overall dimensions of 20 × 37 × 30 mm³ was designed for the finishing tests. The specimen includes three internal channels of 10 mm, 5 mm and 2 mm in diameter and a drop shape section, which was designed as an offset of two external cylinders joined with tangent planes (Fig. 1). The 10 mm diameter hole was then used to clamp the specimen into the FB machine. Five specimen were produced using EOS Titanium Ti64 with an EOSINT M 270 Dual Mode machine. Standard process parameters were used and specimen were grown with the building direction parallel to the z-axis of the specimens.

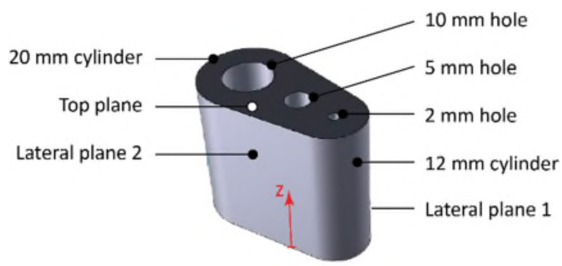

Figure 1. Specimen geometry (overall dimensions 20 × 37 × 30 mm³)

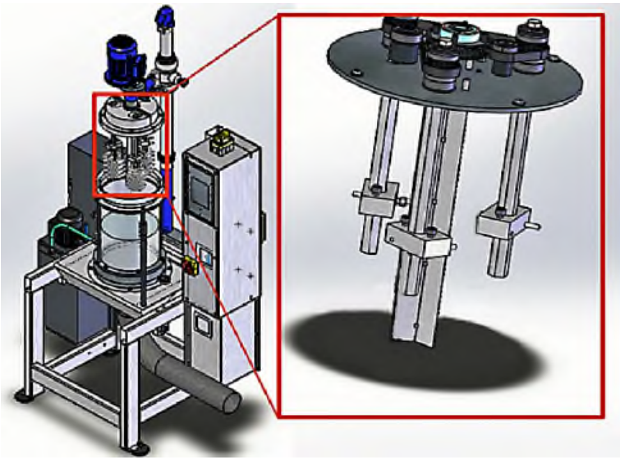

Figure 2. Abrasive Fluidized bed apparatus

2.1. Apparatus and testing

Fluized Bed (FB) device (Fig. 2) is composed by an air supply system and a vertical fluidization column in polymeric material. FB is also equipped with an epicycloidal gearing on the top of the column that allows piece to have revolution and rotation motions around vertical axes. Gearing is moved by an electric motor located on the top of epicycloidal gearing. Into the column, abrasives hit the piece that is immersed in the particles while it is rotating with an arbitrary trajectory. This mechanism leads to surface homogeneity and uniformity at the end of the finishing process. During the experiments, only a minimum amount of air necessary to fluidize the abrasives is supplied, establishing the *minimum fluidization regime*.

Specimens were subjected to the finishing tests in the as-built condition. The abrasive selected for the AFB finishing operation is a cubic wood particle with a size of 5 mm^3. The particle is coated by an abrasive paste (PAICRISTAL ST285) to improve erosion of the specimen surface. Finishing process consisted in rotating the sample clockwise and anti-clockwise while abrasives were fluidizing. Parameters of the finishing process were engine speed of 140 rpm, blower speed of 3520 rpm, distance from specimen and free surface of abrasives of 50 mm and processing time of 12 hours (6 hours clockwise and 6 hours anti-clockwise).

2.2. Characterization tests

As-built specimens were firstly inspected by a CMM machine (DEA IOTA 0101) to evaluate the actual geometry and the repeatability of the process. Then surfaces were analysed by using a profilometer (TalySurf CLI 2000) to evaluate the roughness. The same measurements were made after the finishing process was performed. The analysed features were: external cylinders with diameter of 20 mm and 12 mm, inclined planes, top surface and holes with diameter of 5 mm and 2 mm. Particularly, diameters and roundness of holes and cylinders as well as flatness of external planes were evaluated. Roughness was measured for external surfaces transversely and longitudinally. Measurements were repeated four times to have information about results dispersion.

3. Results and discussion

The average roughness (R_a) values of as-built surfaces were about 12 μm, with a standard deviation of 1.5 μm. Negligible differences between curved and flat surfaces as well as internal or external surfaces were found. After finishing, R_a values of external surfaces were in the range of 0.5-1 μm at the bottom of the sample and about 2 μm on the top. This different behaviour is due to the directionality of the finishing process, since the piece rotation and revolution motions axes are both parallel to the column axis. Thus, the impact of abrasive particles is more effective on the bottom surface of the part.

Table 1. Roughness and dimension before and after finishing

			
Feature		**Before finishing**	**After finishing**
2 mm hole	d (mm)	2.093 *(0.006)*	2.096 *(0.005)*
	Roundness	0.073 *(0.005)*	0.066 *(0.005)*
	R_a (μm)	12.6 *(1.5)*	(-)
5 mm hole	d (mm)	5.094 *(0.013)*	5.110 *(0.010)*
	Roundness	0.043 *(0.004)*	0.032 *(0.03)*
	R_a (μm)	12.9 *(1.1)*	(-)
20 mm cylinder	d (mm)	19.861 *(0.196)*	19.513 *(0.015)*
	Roundness	0.209 *(0.271)*	0.021 *(0.006)*
	R_a (μm)	10.3 *(0.7)*	0.5 *(0.2)*
12 mm cylinder	d (mm)	11.840 *(0.205)*	11.530 *(0.010)*
	Roundness	0.220 *(0.268)*	0.016 *(0.01)*
	R_a (μm)	12.2 *(1.4)*	0.3 *(0.1)*
Lateral planes	Flatness	0.088 *(0.074)*	0.012 *(0.010)*
	R_a (μm)	11.2 *(0.7)*	1.1 (0.5)
Top plane	Flatness	0.026 *(0.01)*	0.022 *(0.01)*
	R_a (μm)	4.6 *(0.5)*	1.9 *(0.2)*

The finishing treatment slightly modified the characteristic dimensions of the sample (Table 1). The dimensional change of the 2 mm and 5 mm holes was negligible, but the increase in the roundness value hints at an uneven material removal by the abrasive. Due to the insufficient finishing of holes, the roughness was not measured. The 20 mm and 12 mm half cylinders were affected by the finishing treatment and experienced an improvement of their roundness values (around 90%). The planarity of the lateral surfaces diminished even though acceptable values (under 0.001) were not obtained.

4. Conclusion and future work

AFB machining process for finishing L-PBF parts was explored in this work and Titanium Ti64 samples with straight channels were built to test the capacity of the process. The effectiveness of the AFB process in the finishing of external curved and flat surfaces was proven and an average surface roughness of less than 2 μm (> 80% decrease) was observed, with slight deviations of the part geometry. This knowledge could be used to define allowances for this finishing process. It is advised to change the orientation of the sample into the column during the process, in order to improve homogeneity. The AFB setup used in this work was not able to finish the holes of the specimen. Further experiments will be carried out changing the specimen geometry, the abrasive media and the trajectory of the part into the fluidized bed, in order to better explore the capabilities of the AFB process for the finishing of internal surfaces/channels.

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