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Enhancing The Quality Of Metal Powder Feedstock For Laser PBF Through Cross-contamination Removal

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Abstract

The presence of impurities in metal powder feedstock for laser powder bed fusion (L-PBF) can strongly affect the mechanical properties of the sintered part. As a matter of fact, the contamination particles trapped in the uniform metal matrix of the raw material, act as a discontinuity and, therefore, as a site for fatigue crack nucleation and growth, leading to a dramatic reduction of the expected fatigue life. While cross-contamination detection is a key parameter to establish the quality level of the metal powder feedstock, its removal is crucial to ensure that the sintered parts will fulfil the service requirements. In this study, metal powder feedstock for laser PBF were intentionally contaminated, submitted to a removal process based on their magnetic properties, through suitably developed equipment. The contaminated and processed powders were characterized by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) techniques.

Introduction

The ability of metal additive manufacturing to build complex and highly customized objects makes it the new gold standard for innovation in automotive, aerospace and biomedical applications [1-3]. Despite all the excitement surrounding the field of metal additive manufacturing, there are several silver linings still limiting the potential of this technology [4-6]. Feedstock cross-contamination and its influence on the properties of the manufactured parts is one of the key issues. Metal powder feedstock has tight tolerances on particles properties such as their shape, size distribution, surface morphology, flowability and composition [7-10]. While issues concerning the powder production steps have been assessed [11], handling and storage of the powder feedstock are still considered critical for the introduction of cross-contamination, not to mention the manufacturing process itself, with the crucial interaction of the powder particles with the equipment walls and the recoater blade [12]. While methods for cross-contamination identification and contamination can be already found in literature [12-13], there is the lack of devices able to interact with the cross-contaminating particles and eventually to separate them from the original feedstock. Therefore, the aim of the present study was to develop a separation system which exploits the physical properties of the metal powder particles, in order to remove the cross-contamination occurring between ferrous and non-ferrous powder feedstock. The development of the concentrator/separator device was based on the following considerations:

- Since the cross-contamination investigation causes the increase of the final cost of the part, the solution must be as cheap as possible;
- The device must not produce sparks;
- The flow volume is variable.

The presented concept method is already used in the food industry to collect ferrous particles from certain food powders and also in the in the mining industry, at a bigger scale [14]. Therefore, available solutions were adapted to a smaller scale in order to improve the quality of the separation process, required by the additive manufacturing industry. The concept is designed with the assumption that the contamination of a ferrous raw powder is due to the presence of non-ferrous granules, or for a non-ferrous raw powder, by the presence of ferrous granules.

Materials and methods

The device's basic principle is to create a certain powder flow path, which will pass through a controlled magnetic field produced by a line of permanent magnets, in order to deviate the ferrous granules (Figure 1). A higher concentration of non-ferrous granules (Ti64) should be collected in the T-side, while the majority of the ferrous granules (MS1) should be found in the M-side of the separated powder container (Figure 1).



Figure 1. Schematic of permanent magnets separator.

The device was tested using different metal powder mixtures and using two configurations: a) magnets in position 2 (P2) as in Figure 1 (close to the powder drop line), and b) magnets in position 3 (P3), with the magnetic field in the middle between the powder drop line and the separation blade at the bottom.

In order to assess the potential of this device, two EOS (Electro Optical System GmbH) virgin powders were considered: (i) MaragingSteel MS1, and (ii) Titanium Ti64. The first one is a maraging steel corresponding to US classification 18 % Ni Maraging 300 and European 1.2709, while the latter is a Ti6Al4V alloy, corresponding to ISO 5832-3, ASTM F1472 and ASTM B348. Powder samples with a controlled cross-contamination were produced as follows: 1) a mixture of 50 wt% Ti6Al4V and 50 wt% maraging steel (Ti64+50MS), and 2) a mixture of Ti6Al4V with 15 wt% maraging steel (Ti64+15MS). The mixtures were filtered through the separator for one and two times, in the as prepared status and in the low humidity status (H), obtained by heat treating the Ti64+50MS powder mixture in a furnace at 60 °C for 2 h. Scanning electron microscopy (SEM) observations were performed on a Zeiss Supra 40 field emission SEM equipped with a Bruker Z200 microanalysis for the energy dispersive spectroscopy (EDS) inspections.

Results and discussion

Powders were accurately spread and attached on stubs for SEM and quantification was performed on five large areas of each stub at low magnification (200x) using 20 keV accelerating voltage. Typical micrographs of the virgin powders are shown in Figure 2.



Figure 2. SEM backscattered electrons micrographs of the virgin Ti64 (left) and MS (right) powders.

The chemical compositions of the contaminated and processed powders were checked by collecting five EDS spectra on areas. The labels and details of all the characterized samples are reported in Table 1.

Name	Separation cycles	Side	Heat treatment	Magnets Position
1T	1	Non-ferrous	-	2
1T_H	1	Non-ferrous	Yes	2
2T	2	Non-ferrous	-	2
1M	1	Ferrous	-	2
1M_H	1	Ferrous	Yes	2
2M	2	Ferrous	-	2
1M_P3	1	Ferrous	-	3
1T_P3	1	Non-ferrous	-	3
1T_15	1	Non-ferrous	-	2
1M_15	1	Ferrous	-	2
1T_15_P3	1	Non-ferrous	-	3
1M_15_P3	1	Ferrous	-	3

Table 1. Labels and details of all the characterized samples processed by the developed device.

Table 2 shows the results of the first trials on the Ti64+50MS mixture and, besides very limited fluctuations of the titanium and iron mean values, no remarkable differences can be observed between the original powder mixture and all the samples resulting from the separations.

Sample	Fe (wt%)	Ti (wt%)
Ti64+50MS	23 + 3	63 + 3
(Reference)	23 ± 3	03 ± 3
1T	23 ± 3	65 ± 3
1T_H	23 ± 3	63 ± 3
2T	24 ± 1	64 ± 1
1M	26 ± 4	61 ± 4
1M_H	28 ± 5	58 ± 7
2M	23 ± 1	64 ± 1

Table 2. Results of the EDS quantification performed on Ti64+50MS samples after separation in P2 condition.

However, by increasing the distance between the powder drop line and the position of the magnets, more space is given to the free fall of the metal powder particles which can separate from each other in a more efficient way, enhancing the action of the magnetic field, as shown by the "P3" results in Table 3. On the magnetic field side ("M"), indeed, a higher iron and a lower titanium content are observed, respectively.

 Table 3. Results of the EDS quantification performed on Ti64+50MS samples after separation in P3 condition.

Sample	Fe (wt%)	Ti (wt%)
Ti64+50MS	23 ± 3	63 ± 3
1M_P3	32 ± 5	51 ± 6
1T_P3	21 ± 2	64 ± 3

In order to check if the separation performance could be influenced by the tendency of the maraging steel particles to aggregate, a mixture of Ti64 with 15 wt% of MS only, was prepared and tested on the device. Table 4 shows that using the first configuration, or rather magnets in position 2, results from EDS quantification (samples 1T_15 and 1M_15 in Table 4) did not show any significant deviation from the original mixed powder.

Table 4. Results of the EDS quantification performed on Ti64+15MS2 samples after separation in the two magnets positions conditions.

Sample	Fe (wt%)	Ti (wt%)
Ti64+15MS2 (Reference)	5.6 ± 1.6	84 ± 3
1T_15	5.4 ± 0.4	84 ± 1
1M_15	5.4 ± 1.4	84 ± 1
1T_15_P3	5.3 ± 1.2	82 ± 2
1M_15_P3	7.5 ± 1.2	80 ± 1

However, by lowering the magnets line (position 3) the performance of the device is enhanced in terms of concentration of MS particles, since as highlighted in Table 4, the 1M_15_P3 sample shows an iron content which is slightly higher than the original one (Ti64+15MS2).

Conclusions

The trial tests performed on the cross-contamination separation device showed that the position of the magnets, and the related magnetic field, has a remarkable influence on the performance of the device. On the other hand, the tendency of the maraging steel powder particles to form aggregates showed to not have significant implications on the performance. These results open the door to a redesign of the separation device and to the next standard for cross-contamination free metal powder feedstock.

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