Challenges and quality implications of feedstock cross-contamination of metal powders: an industrial perspective

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INTRODUCTION

Amongst the challenges of bringing Additive Manufacturing (AM) from lab to market is not only the technical issues of production capabilities, scalability and identification of proper applications. High standards are needed in the tool-shop environments in order to ensure consistent production of multiple parts across machines, operators, and manufacturing facilities. AM dedicated laboratories and production sites are becoming more common and at the same time, new questions arise in regard to requirements and how to meet these high standards, e.g. achieving constant characteristics of the powders in connection to the machine parameters and work environment [1]. In this context, this paper focuses on the challenges faced when establishing such AM facilities, e.g. for production or research, and it aims to specifically address the potential side-effects related to cross-contamination of powder feedstock and its effect on precision and quality of the final parts.

Metal powder particles used in powder-based AM processes are in the range of Ø20-100 µm in size and are easily subjected to migration when entering an air flow. During powder handling, e.g. build chamber cleaning operations, refill of reservoir with virgin powder, etc, the particles can enter linger in the surrounding environment for prolonged amounts of time. This will increase the risk of a powder particles to stick to the clothes of machine operators who then carry them in the surrounding environment, possibly contaminating subsequent production. This has been acknowledged mainly with direct experience. In some cases, the microstructure analysis of a component showed the presence of foreign material who could not really been explained. In fact, the inclusion's material has not been in use in the facility since more than six months suggesting that it might not be a unique case.

Defects within metal components made with powder bed fusion processes are widely studied, e.g. porosities, micro-cracking and poor particle bonding. Their negative effect on part properties, e.g. tensile strength and fatigue, is widely acknowledged and reported largely in academic literature [2]. Despite this, little could be found in literature about categorizing in-situ cross-contamination of powders as a possible cause of defects within the part, and as a main factor affecting quality, precision and mechanical properties of AM parts. It is commonly accepted that cross-contamination of feedstock powders *may* affect the properties of the final part, for example contributing to inconsistent layer adhesion due to difference in melting temperature[3] but the extent of the problem is still dubious.

As the development of AM increases by the day, more production sites are expected to expand and adapt to a more AM inclusive environment. In this context, single-material machine set-ups are advisable for high

performance application components, e.g. aerospace [4], [5], however this may represent a challenge for research facilities with a smaller capacity but a wide portfolio of products and materials.
This paper aims to recognize and ordain appropriate measures with relation to the hidden risks of cross-contamination of the powder from which geometry is consolidated in powder-bed fusion systems and to present a possible framework for the prevention of in-situ cross-contamination of feedstock.

AM PROCESS LIFE CYCLE AND KEY INFLUENCING FACTORS TO PART QUALITY; AN OVERVIEW

Quality control is a widely used resources within manufacturing processes. Mapping the whole manufacturing process is a necessity to gain in depth knowledge of influencing factors within the process and to being able to reach high standards of production. In literature a number of studies in this area that have attempted to create a comprehensive overview of the AM process and Figure 1 shows in broad terms, what are the key aspects that have an impact on the final part.

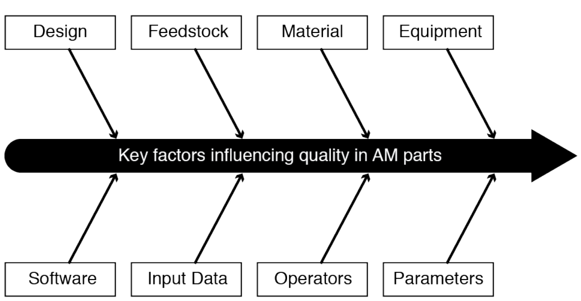

Figure 1 Main influencing factors on the quality of the final AM part

In Figure 1 the main factors influencing the quality of AM parts are listed as: design, feedstock, material, equipment, software, input data, operators and process parameters. All of these have equal importance in the process, however in this paper, only the aspects related to the feedstock and the materials will be covered. A reliable certified material supplier, in-process monitoring and testing after the build are fundamental when aiming for part quality, reliability and to achieve high process repeatability. Especially so, with the rise of AM as a direct manufacturing technology and with increasing demands for compliance. A growing number of powder manufacturers are now specializing in the production of AM powders and they are becoming more aware of the necessary preventive measures in order to avoid accidental cross-contamination of non-compatible feedstock and defects. In fact, the quality of the incoming materials in the machine are critically important to the outcome of the part. On top of that, the material behavior is followed along during production, with in-process monitoring procedures, and afterwards by means of destructive or non-destructive testing, where the part is cut up and inspected for inclusions and defects.

CHALLENGES RELATED TO METAL POWDER HANDLING

In an ideal scenario of AM production, there would be one powder metal machine used for a single metal powder material, in order to minimize the occurrence of in-situ cross-contamination during production. In many cases, it is not uncommon to find multiple powder metal machines operating a single material each on the same production floor. Challenges however start to occur when materials of different nature are used, especially metals with different characteristics, e.g. reactive and non-reactive. In this context the authors believe that there is a poor understanding of the behavior of the powders in the air and of how this could affect the quality of the components. During the handling of the metal powders, due to the small size of the particles, the material may enter the air flow and circulate in the surrounding area. Additionally, when operating the machine, technicians become exposed to powders increasing the likelihood of carrying the different powders with them from one machine to the others. Although appropriate, and strict, procedures can help in these scenarios, the risk of contamination still exists and, because of the unpredictability of the particles behaviors in the air, the effects of it cannot be controlled properly. For this reason, the authors believe it is necessary to map the intermediate steps of the powder handling within the production process, highlight the points where risks of contamination are higher and come up with solutions to minimize the contamination during these operations.

<u>Mapping the critical steps during the process of metal powder handling</u>

From the moment the material arrives to the production facility to the moment when the AM part is manufactured; the operator has to carry out a series of steps that require different degrees of exposure to metal powders. The most critical steps are during the machine preparation time, e.g. removing the build plate, cleaning the build envelope and replacing the build plate. During these steps the operator has a direct contact with the interior of the machine. A summary of these steps is shown in Table 1, which highlights the most critical steps.

Table 1 Steps required for machine preparation. Highlighted are the critical steps where the operator is directly in contact with the powder and where the powders are at risk of entering the air flow.

	Operation	**Direct exposure to powders**
1	Machine cool down	No
2	Remove excess powder around the part	No
3	Open machine	Yes
4	Remove build plate from machine	Yes
5	Transport build plate to right location	Yes
6	Clean machine from excess powder	Yes
7	Insert new build plate	Yes
8	Calibrate the machine	Yes
9	Close machine	No
10	Refill machine with virgin powder	No

A PRAGMATIC APPROACH FOR THE AVOIDANCE OF CROSS-CONTAMINATION IN PRODUCTION R&D FACILITY

AMEXCI is a Swedish startup, privately owned by 11 different companies, 10 of which are big players in the global manufacturing industry [6]. Recently AMEXCI has built a new workshop facility that will be used for R&D purposes in the field of AM. The current capacity for powder systems is: one EOS P396 (polymer), two EOS M290 (one for reactive and one for non-

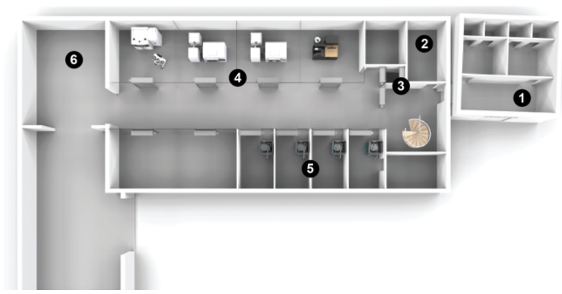

Figure 2 Schematic of the workshop floor. (1) Changing rooms, (2) Preparation room, (3) Air lock, (4) Machine rooms, (5) powder rooms, (6) Post processing.

reactive metals), one Aconity MIDI. Due to the variety of industries served by the

Figure 3 Workshop with the machines located in separated rooms with glass walls. Each room has a roll-up door.

company, the type of materials will vary over time. It is therefore paramount for the company to have an impeccable plan.

In this regard AMEXCI, having had the possibility of building the workshop from scratch, has adopted various measures in order to minimize, if not avoid, the cross-contamination of the metal powders. The measures taken involve both the construction of the workshop and the handling procedures. These can be summarized as following:

- Each AM machine is in a room separate from the others (Figure 2 and Figure 3**Error! Reference source not found.**)
- Each powder material has its own preparation and handling room (Figure 2)
- Each room has an appropriate ventilation system. This pushes the powders top-down and sucks them from the lower level to the back of the room
- Each room has a roll-up door to prevent agitation of air and to reduce the stirring of powders particles (Figure 3)
- Operators have to go through an air lock when entering the workshop and every time before entering another room with machines or powders
- A monitor system has been installed to keep track of the powder activity in the different areas of the workshop over time and determine the behavior of the powders

CONCLUSIONS

The paper discussed the issues related to cross-contamination of metal powder in production R&D facilities and proposed an approach to limiting the occurrence of this phenomenon by separating each machine in a different room and by establishing a strict internal procedure for handling. Although the effect of cross-contamination of powders is not widely discussed or addressed in literature, we believe it plays a very important role in the industry as it may have significant effects on critical components leading to cracks and ultimate failures.

FUTURE WORK

Track cross-contaminants throughout the facility would be the next step in order to better understand the challenge of cross-contamination and particle behavior within an AM production facility. Although challenging to track the amount of contaminant that will be transferred, methods similar to those used within the food-production industry could be used. This approach would be useful to track the cross-contamination introduced by the operator.

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