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New concept for multi-material processing with SLM

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Abstract

Additive Manufacturing (AM) enters industry and thus into new challenges to cope with standard requirements of industrial manufacturing processes. AM-processes are far less simple as it might be expected due to the absence of collision geometries and cutting forces. Additionally and in an even more complex manner, manufacturing of multi-material components with today's AM facilities is still lacking. Compared with a standard single material SLM process, the main challenge of multi-material processing is to achieve the same required work piece quality. Therefore, new requirements and concepts, regarding powder handling and deposition, have to be defined and satisfied, which are not only more complex, but also interrelated to each other. In this paper, a new concept for processing multi-materials with SLM is recommended, based on state-of-the-art of science and technology reviews.

Keywords: Multi-material processing; Selective Laser Melting (SLM); Powder Feed System;

1. Introduction

In a conventional selective laser melting process, a thin layer of powder is deposited onto a part-build area, as explain in Santos et al., 2006. To form solidified layers, a laser beam, which is guided by galvano mirrors, is scanned onto the powder bed, whereas the powder in other areas remains loose. Another powder layer is deposited after the building-area sinks one-layer thickness. This procedure is repeated until the workpiece is completely built.

To satisfy modern requirements, such as specific material properties for the end-product, low production times, more freedom of design and high material recycling rates, different materials have to be combined and investigated in conjunction with a powder feed system for the selective laser melting process, as explained in the research of Ott, 2012. Industrial applications, which have such specific need for SLM-produced multi-material products, are pressure die-castings with an outer shell made out of H13 tool steel

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to provide the structural strength and a copper core to reduce the thermal resistance, according to Al-Jamal et al., 2008. Similar copper-steel bimetallic SLM-samples, which could have an application in the fields of fusion reactors, conformal cooling channels, automobiles, rail and aviation industries, cookware and wires for high field pulsed magnets, have been analysed in the research of Liu et al., 2014 and Sing et al., 2015. Furthermore, the fracture behaviour of SLM-produced MS1-H13 hybrid hard steels have also been investigated by Cyr et al., 2018 and indicates the direction of future researches in this specific field.
In general, three gradations in conjunction with the SLM process are differed: 1-D mono-material, 2-D hybrid (sandwich-like) and 3-D multi-material parts or components, as illustrated in Fig. 1, referring to Ott, 2012. Based on extensive reviews, regarding the state-of-the-art, a new powder-deposition-concept for real 3-D multi-material components, in conjunction with a powderbed-based process (e.g. SLM), has been proposed and explained in detail.

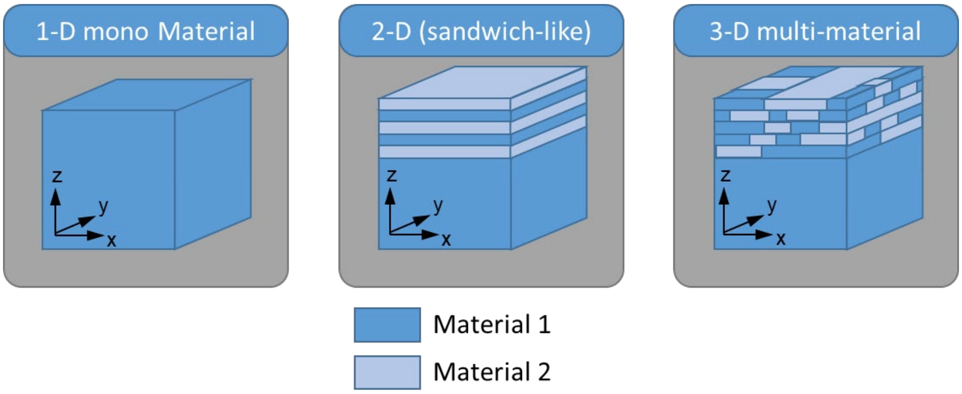

Fig. 1. Three gradations in conjunction with the SLM process are differed, according to Ott, 2012

2. Analyzed concepts and state of the art

For multi-material processing with SLM, a concept, which accurately deposits and melts the powder is extremely necessary, especially for the usage of two separate materials with completely different material properties. Therefore, different drafts from several researchers and inventors have been analysed in this chapter.

A procedure and an appliance to manufacture multi-material parts, based on their 3-D data, have been patented by Meiners and Wissenbach, 2009. Different powders, meaning more than two materials, can be locally deposit in the scanning plane *(XY)* by powder nozzles, according to the specific material data of the part, as illustrated in Fig. 2 left-hand side. Using such an appliance with more than two different materials would increase the complexity with the material intersections and increase the contaminated powder leftovers drastically. The powder recycling advantage of a SLM process would be devastated.

A 2-D hybrid (sandwich-like) procedure, regarding several powder rakes, have been registered by Krol et al., 2018 (see Fig. 2 right-hand side). Also in this case, the material intersections with increasing powder thickness by each rake and the useless mixed powder leftovers after processing, clearly point out the non-satisfied multi-material process requirements for SLM.

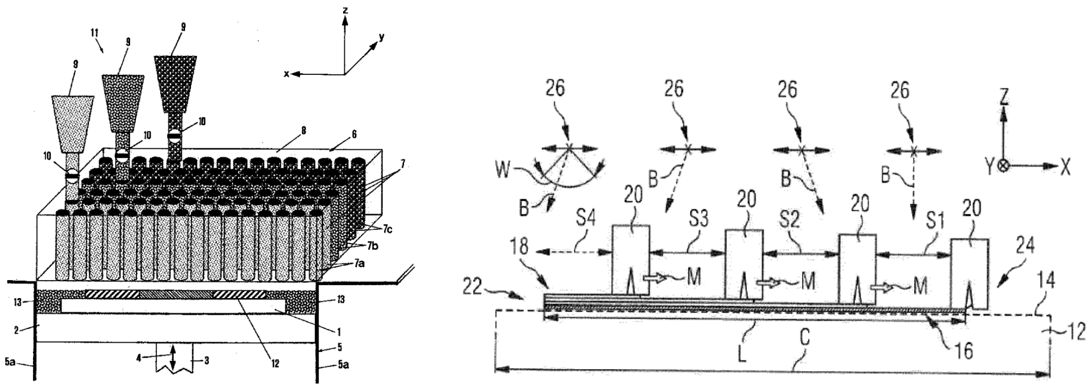

Fig. 2. Powder feed system according to Meiners and Wissenbach, 2009 (left picture) and powder application devices with several powder rakes, referring to Krol et al., 2018 (right-hand side)

Another incomplete multi-material powder feed system, regarding the contaminations through powder mixing during the whole process, has been proposed by Knittel and Bilhe, 2016. The missing powder outlets between the two powder containers can be noticed from Fig. 3 on the left-hand side. A similar, but, more advanced powder container application has been developed by Fackler, 2018. The powder outlets are still not mentioned but the flexible powder containers can be removed and replaced by different material powders during the running process, as shown in Fig. 3 on the right-hand side. The containers include material specific digital data and parameters, such as material type, grain size, material quality, minimum and maximum thickness for processing. With both systems, only hybrid or sandwich-structured components are possible to manufacture.

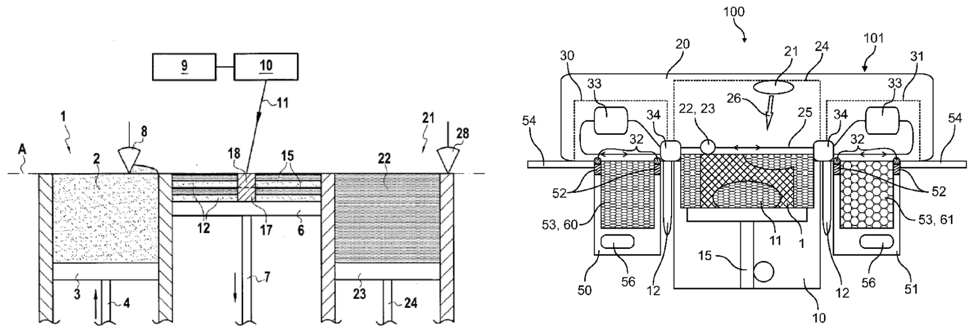

Fig. 3. Incomplete multi-material AM-systems according to Knittel and Bilhe, 2016 (left-hand side) and Fackler, 2018 (right picture), regarding the powder contaminations for sandwich-structured components

To solve the last explained problem with in-process powder mixing and the missing powder outlets to a certain extent, Ljungblad, 2013 have developed rotating powder containers on each side, which are using the gravitational force to deposit powder on each side of the rake, as illustrated in Fig. 4 on the left-hand side. This application is also useable for different materials. A similar and less complex powder delivery system, which just use the gravitation field and controlled electromagnetic valves to portion the powder amount for both materials, as indicated in Fig. 4 on the right-hand side, have been registered by Yao et al., 2016. Also with those two systems, only hybrid or sandwich-structured components are possible to manufacture.

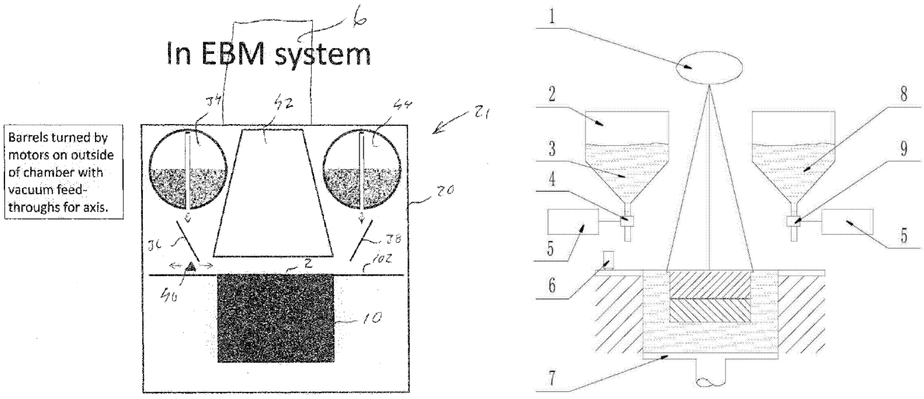

Fig. 4. Rotating powder containers (left-side) according to Ljungblad, 2013 and controlled electromagnetic valves (right-hand side) according to Yao et al., 2016 to deposit powder on each side of the rake

A kind of revolver powder delivery and build plate rotation-system for the usage of more than two materials has been developed by Yang et al., 2017a and Yang et al., 2017b, as shown in Fig. 5 on the left- and right-hand side with top- and front-view, respectively. Also in those cases, the main problem is the powder contaminations during the process and post-process, as mentioned earlier. With those systems, only sandwich-like or simple hybrid components can be manufactured.

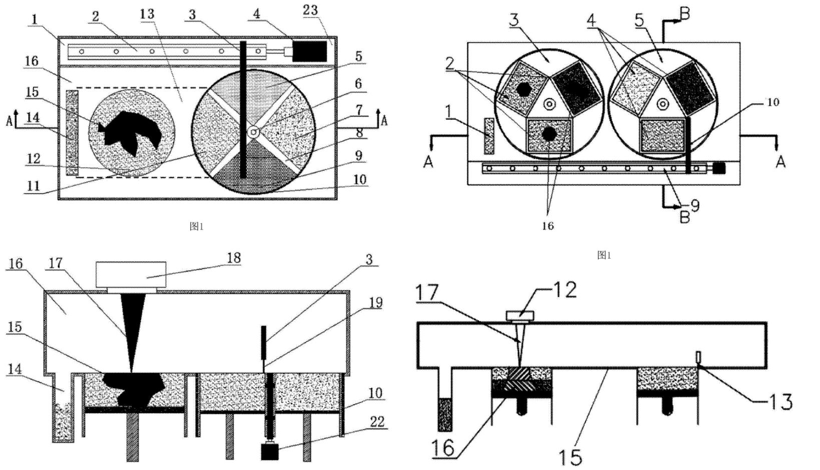

Fig. 5. Revolver powder delivery system (left pictures) according to Yang et al., 2017a and revolver powder system combined with a build plate rotation-system (right-hand side), referring to Yang et al., 2017b

A kind of suction cleaning and blowing unit has been combined with a powder bed process for multi-material components by Meiners et al., 2001, as illustrated in Fig. 6. A base powder or layer is deposited by the rake unit and the second material can be delivered by a feeding system, next to the suction cleaning and blowing unit. Regardless the contamination problem with a suction cleaning and blowing unit, this process allows also only sandwich-like or hybrid parts to manufacture, but real 3-D multi-materials are not possible to process.

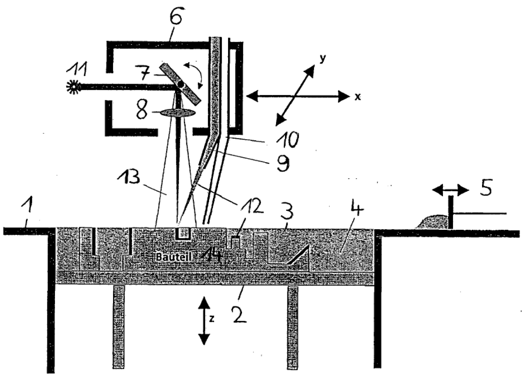

Fig. 6. A suction cleaning and blowing unit, combined with a powder bed multi-material process according to Meiners et al., 2001

To overcome the hybrid/2D process problem, an apparatus, which was originally developed for metal matrix composites by Beetz, 2018, contains a 3-D printing application with polymers, resin or ceramics as a second material. The local deposition of the powders is realised by using a printhead device, as shown in Fig. 7. The polymer can also act as a support feature, to hold up the molten metal, according to Beetz, 2018. The material intersections and the corresponding bonding of the melted "powder hills" can be identified as the main issue, regardless the mixed powder after processing, which destroys the recycling advantage of SLM.

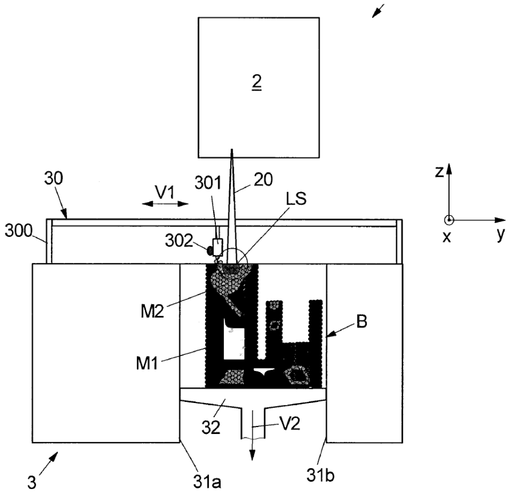

Fig. 7. 3-D printing application originally developed for metal matrix composites and possible extensions to 2D/3D multi material processes, according to Beetz, 2018

Based on the analysis of the powder feed systems in the studies of Al-Jamal et al., 2008 and Regenfuss et al., 2007 with copper and silver, a further development has been created by Sun et al., 2017. Two powder containers have been combined in a moving powder feed system unit, which can also be relatively moved in the other scan direction, as shown in the Fig. 8. Also in this case, the mixed powder after processing and the intersections between the deposited “powder hills” of the same material and the additional one are identified as the main problems. The powder feed system can only be moved slowly to manufacture complex 3D multi-material components, especially for high material changing frequencies, e.g. small chessboard with alternating materials.

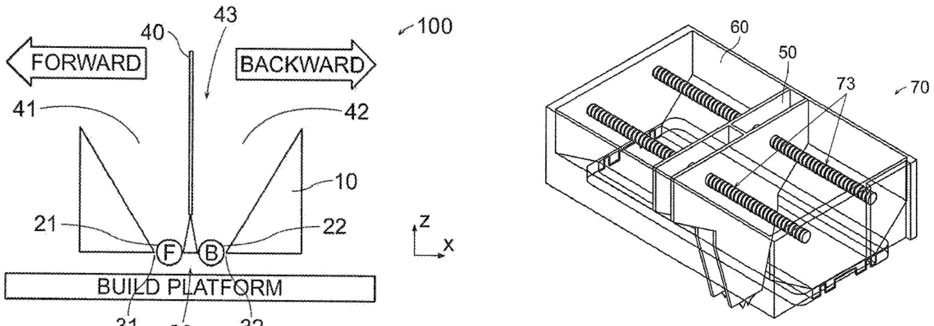

Fig. 8. Combined powder containers, which can be relatively moved in the y scan direction, referring to Sun et al., 2017

3. Discussion and suggested concept of multi-material SLM processing

In this chapter, the main five issues are summarized and used to suggest a new concept for multi-material processing with SLM and any powderbed-based process.

3.1. Summarized issues

As already analysed and explained in the last chapter, all of the mentioned powder feed systems have at least one of those five issues:

- mixed/contaminated powder during processing with two materials
- mixed/contaminated powder after processing with two materials (recycling problem)
- only hybrid or sandwich-structured components are possible to manufacture
- the intersection between the deposited “powder hills” of the same material and the additional one
- slow material changing frequencies

3.2. New concept for multi-material processing

Generally, only gravitational powder feed systems are useful for multi-material processing in SLM regarding the powder contaminations. A rake system should be avoided due to the fact, that there is always a powder avalanche in front of the rake, which will mix all the other involved material powders. To reduce the powder loss after the process, a so-called “cheap dummy” powder has to be used, which fills in the non-scanned vacancies on the build plate. For accurate powder positioning and high material changing frequencies, a kind of dot matrix needle printer with several needles in a row for each different powder is suggested. Taking the gravitational powder feed system into account, the matrix needle printer has to be combined with the powder container as a moving unit, as shown in Fig. 10. The needles itself have to move relatively to each other and reach the nearest point for powder deposition according to the CAD- and material-data of the component, as illustrated in Fig. 11. Almost certainly, the capillary nozzles have to be vibration-controlled for more accurate powder dispending, as well analysed and explained in Stichel et al., 2014. Furthermore, a precise powder-stamp with a non-adhesive surface has been suggested to finish the powder layering process and to overcome the intersection issue between the deposited "powder hills" of the same material and the additional one.

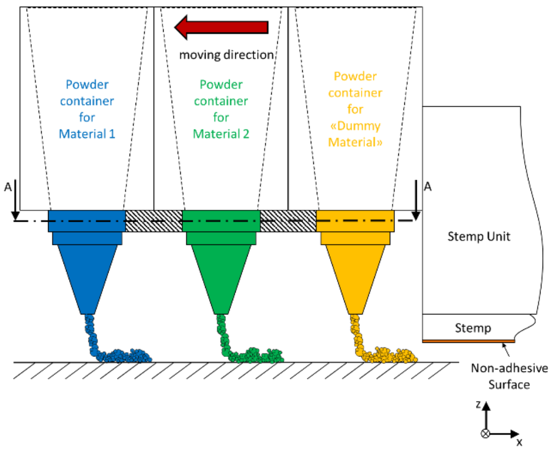

Fig. 9. Matrix needle printer, combined with the powder containers as a moving unit and stemp unit (side view), to overcome the five mentioned issues

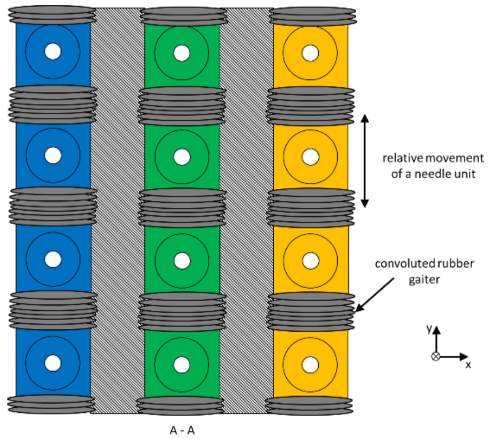

Fig. 10. Relatively movement of the needles, to reach the nearest point for powder dispending and increase the material changing frequencies (top view – sectional drawing)

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