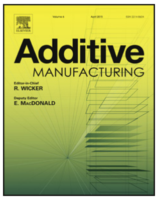
Additive Manufacturing 18 (2017) 228–255

Contents lists available at ScienceDirect

Additive Manufacturing

journal homepage: www.elsevier.com/locate/addma



Review

An overview of powder granulometry on feedstock and part performance in the selective laser melting process

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ARTICLE INFO

Article history:
Received 21 March 2017
Received in revised form
27 September 2017
Accepted 8 October 2017
Available online 13 October 2017

Keywords:
Metal additive manufacturing
Selective laser melting
Powder processing
Powder characteristics
Powder granulometry

ABSTRACT

Metal Additive Manufacturing (AM) has begun its revolution in various high value industry sectors through enabling design freedom and alleviating laborious machining operations during the production of geometrically complex components. The use of powder bed fusion (PBF) techniques such as Selective Laser Melting (SLM) also promotes material efficiency where unfused granular particles are recyclable after each forming operation in contrast to conventional subtractive methods. However, powder characteristics tend to deviate from their pre-process state following different stages of the process which could affect feedstock behaviour and final part quality. In particular, primary feedstock characteristics including granulometry and morphology must be tightly controlled due to their influence on powder flow and packing behaviour as well as other corresponding attributes which altogether affect material deposition and subsequent laser consolidation. Despite ongoing research efforts which focused strongly on driving process refinement steps to optimise the SLM process, it is also critical to understand the level of material sensitivity towards part forming due to granulometry changes and tackle various reliability as well as quality issues related to powder variation in order to further expand the industrial adoption of the metal additive technique. In this review, the current progress of Metal AM feedstock and various powder characteristics related to the Selective Laser Melting process will be addressed, with a focus on the influence of powder granulometry on feedstock and final part properties.

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https://doi.org/10.1016/j.addma.2017.10.011

1. Introduction to metal AM

Additive Manufacturing (AM) has observed increasing adoption from medical, aerospace and automotive industries to manufacture prototypes and functional components with complex structures while eliminating the geometrical constraints constantly faced by traditional machining techniques. AM processes were first introduced in the late 1980′s as Rapid Prototyping (RP) solutions based on various layer building and material consolidation approaches to produce quick design-to-part models for visualisation and prototyping purposes. The versatile technology offers a wide range of material consolidation mechanisms including Stereolithography (SLA), Laminated Object Manufacturing (LOM), Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS) and 3D Printing (3DP) which share a common working principle of Layer Manufacturing (LM) [1]. After more than two decades of AM existence, technology advancements and stringent industrial demands forced a shift in AM approach towards Rapid Manufacturing (RM) and Rapid Tooling (RT), whereby conventional RP techniques extended their capabilities to produce directly useable components with material and mechanical performance comparable to conventional manufacturing. Currently, AM technology is focused on developing practical end-use industrial applications such as injection moulding tools, dental implants and aerospace engine components. Metal AM processes are strongly targeted at achieving these goals to produce high value components in conjunction with design flexibility, multi-material integration as well as light weighting possibilities.

1.1. *Metal AM materials and classification*

Powder, wire and sheet materials are various forms of feedstock utilised in metal AM processes which also differentiate the respective construction behaviours and material binding modes of the commercialised techniques (Refer to Fig. 1). Majority of the metal AM processes consist of powder-based systems including Powder Bed Fusion (PBF), Direct Energy Deposition (DED) and Binder Jetting which utilise granular powder as the primary source of material during part forming. Among these processes, PBF and DED techniques execute direct melting of powder materials to achieve fully dense parts using high energy sources (E.g. laser or electron beam) while Binder Jetting coagulates powder particles with adhesive agents before carrying out post sintering and secondary infiltration for part density restoration. Material depositions of powder-based methods are also dissimilar in which PBF and Binder Jetting processes involve the coating of feedstock onto a bed substrate prior to material consolidation while DED utilises a coaxial nozzle and beam to perform powder delivery and melting almost simultaneously. In particular, the class of PBF techniques including Selective Laser Melting (SLM) and Electron Beam Melting (EBM) processes are typically preferred routes for the direct fabrication of high quality metallic parts [2]. In comparison, SLM utilises an Nd: YAG fibre laser (∼200–400 W) under an inert gas environment (E.g. Ar or N) while EBM requires a focused electron beam (∼60 kW) within vacuum conditions [3]. Although both techniques are capable of producing near net shape metallic components, SLM generally manufactures higher precision parts with better as-built surface quality than EBM but often at the expense of longer build times and higher residual stresses [4]. While the primary reason could be due to the relatively finer powder sizes used in SLM, the influence of size distribution (granulometry) on the powder behaviour during process build-up and the resulting part quality remains unclear.

1.2. *SLM research*

It is well known to the metal AM community that SLM technology and other PBF processes are sensitive to both process and material inputs used prior to part build-up [5]. Accordingly, many published works have concentrated on addressing the major key process parameters including laser power, scan speed, layer thickness and hatch distance which requires strategic control to generate suitable energy intensities for processing different types of metallic materials [6–8]. Existing studies also reviewed on the mechanical properties of SLM produced parts, variations in part performance due to different orientation, build layouts, scan strategies as well as common issues and defects encountered during SLM processing which are strongly tied to its complex metallurgical phenomenon [1,9–13]. To resolve process complexity and understand the thermo-mechanical interactions occurring in SLM, numerous numerical modelling simulations and finite element approaches have also been developed and reviewed by King et al. [14]. With respect to the materials used in SLM, finer sized powders are preferred to achieve parts with better resolution when used in conjunction with reduced layer thicknesses during processing [9]. However, less emphasis was placed on the influence of powder size distribution as compared to its importance in the study of conventional sintering [15]. More recently, researchers are beginning to spend considerable efforts in quantifying feedstock performance used in metal AM which illustrated several key characteristics