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Influence of the shielding gas flow on the removal of process by-products in the selective laser melting process

Alexander Ladewig[a,*], Georg Schlick[a], Maximilian Fisser[a], Volker Schulze[b], Uwe Glatzel[c]

[a] MTU Aero Engines AG, Germany
[b] wbk Institute of Production Science, Karlsruhe Institute of Technology, Germany
[c] Chair of Metals and Alloys, University of Bayreuth, Germany

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ABSTRACT

Selective laser melting is a promising additive manufacturing technology for the production of complex metal components. The technique uses metallic powder as a starting material and a laser for melting and building-up parts layer by layer. One crucial factor influencing the process stability and therefore the part quality is the shielding gas flow. In addition to the shielding properties of the inert atmosphere the gas flow is responsible for the removal of process by-products like spatter and welding fumes originating from the process zone. Insufficient removal or inhomogeneous gas flow distribution may lead to increased interaction between laser and process by-products. Consequences are attenuation of the laser spot as well as redeposition of this by-products on surfaces which are exposed to the laser afterwards. Firstly, a conclusion on all known process by-products is drawn. Secondly, based on these considerations the uniformity of the gas flow is investigated by the width of single welds. Furthermore process deviations are provoked by unfavorable gas flow conditions. Thirdly, the impact of this deviations on building surface and part quality is investigated by 3D confocal microscopy, microsections and ultrasonic testing. Finally, theoretical approach for the formation of these process deviations and arising material defects is presented.

1. Introduction

Freedom of design, reduction of mass and processing of new materials are major arguments for the development of additive manufacturing. Especially manufacturers of aircraft propulsion systems are interested in this field. MTU Aero Engines is ramping up series production of parts for a new engine program [1]. Original equipment manufacturers like GE Aviation and Pratt & Whitney are pushing the technology towards series production as well [2].

One of the most spread powder bed fusion additive manufacturing technologies for metallic parts is the selective laser melting process (SLM). This technique uses a laser beam in order to locally melt metallic powder which is applied layerwise. The basic steps of the selective laser melting process are shown in Fig. 1. By these means a near net shape part is produced consisting of layers. Layer thicknesses are commonly between 20 and 50 microns [3].

In general, the SLM process runs in a closed build chamber filled with shielding gas. Typically, this shielding gas is recirculated in a closed circuit. This leads to a shielding gas flow in the process chamber which can be described either as an undirected or a directed flow. Possible implementations are either an undirected flow from the top of the build chamber as in an Eosint M270 or a directed flow over the powder bed as in an EOS Eosint M280 and the different version of SLM 250 Machines (e.g., MTT Realizer 250, SLM Solutions SLM 250).

The characteristics of the shielding gas atmosphere and the implementation of the shielding gas flow are substantial factors influencing the quality of the selective laser melting process. Firstly, inert atmosphere shields the process zone from reactive gasses in order to prevent chemical reactions like oxidation or nitration [4]. Secondly, the gas flow removes process by-products from the process zone to enable an undisturbed process.

Ferrar et al. [5] and Kong et al. [6] link the gas flow uniformity on a MTT Realizer SLM 250 to the part quality. Moreover, both papers suggest that changing the gas guidance system could improve the part quality. The results of both publications show an unevenly distributed gas flow. In particular, a decreased gas flow velocity

* Corresponding author.
E-mail address: Alexander.Ladewig@mtu.de (A. Ladewig).

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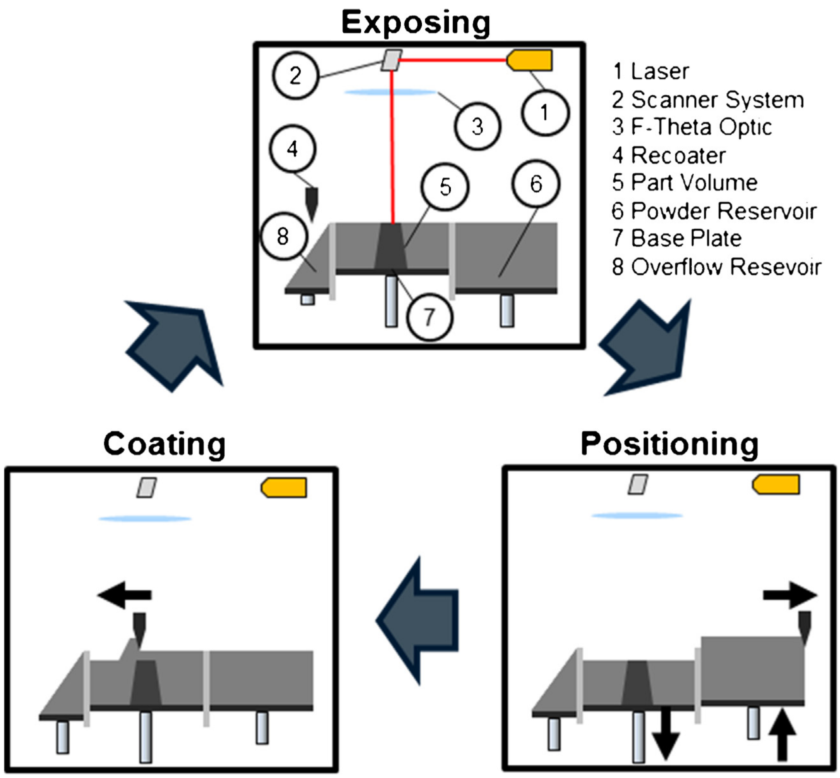

Fig. 1. Basic Principle of selective laser beam melting at EOS Eosint M280 machine.

is observed near the gas outlet. The authors emphasize the influence of the gas flow on the density and surface morphology of the built parts.

The two crucial factors for the part quality are laser attenuation induced by by-products in the laser path and material accumulations caused by redeposition of this by-products. Both factors are influenced by the gas flow. Therefore this study focusses on the gas flow uniformity and rate and investigates their influence on single laser tracks and the hatching process during the building procedure of bulk material.

2. Theoretical basics: process by-products and their influence on the SLM process

Several by-products are produced during selective laser melting. These by-products may significantly disturb the melting process. To counteract these disturbances it is necessary to understand the by-products and their influence on the process. Fig. 2 shows the typical by-products occurring during selective laser melting.

2.1. Formation of process by-products

2.1.1. Welding plume

The so called welding plume essentially consists of two process by-products, a plasma plume and metal vapor.

In high power laser processes the gas directly above the interaction zone becomes ionized and a plasma plume is established. Beck et al. [7] investigate the plasma plume for a deep penetration welding process with a CO_2 laser.

However, there is not only plasma in the welding plume. Due to the high energy density of the focused laser beam the melt pool reaches the evaporation point of certain alloying elements in the center of the laser spot. As a consequence, vaporized metal is ruptured out of the melt pool [3].

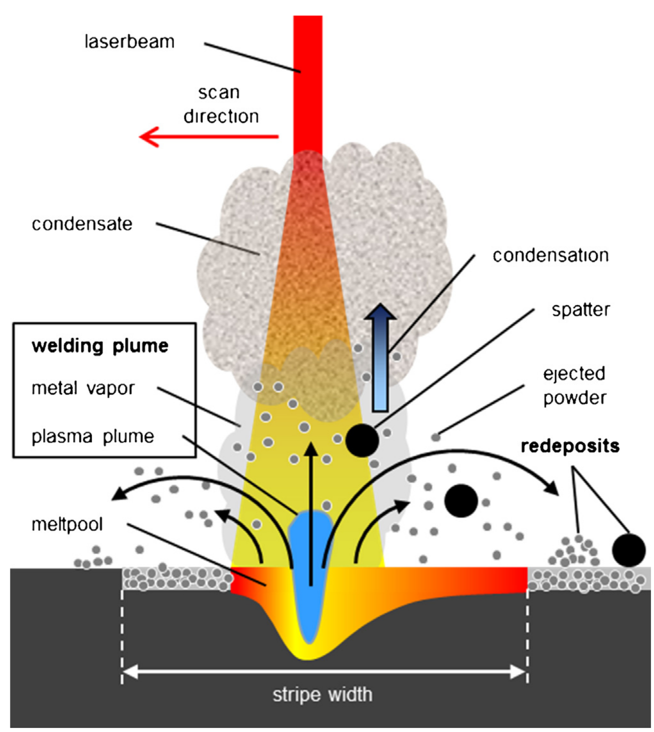

Fig. 2. Schematic representation of possible process by-products.

The vaporized metal is cooled down very quickly and condensates, forming particles with diameters between 10 nm and 150 nm. These particles can agglomerate and aggregate to different orders of magnitude depending on the duration of the condensation process [8,9].