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Process Parameter Generation of Nickel Based Alloys using Predictive Software Tool

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Abstract: A current issue in the democratization of metal based additive manufacturing is the rapid and reliable development of process parameters for a range of alloys and a range of dependent and independent processing conditions. Current process parameter development approaches include a wide of strategies and multi-variable optimization methods. These methods can be costly from a time, material, and engineering knowledge perspective. A different approach is possible using a predictive software tool that takes key inputs and returns key process parameters for initial use. This tool is validated on two nickel based super alloys and benchmarked against literature results of a third. This tool is of particular interest to industries such as aerospace that routinely use a wide range of high temperature alloys in their products and manufacturing workflows.

Keywords: Software based parameter development, OPTOMET, Selective Laser Melting, Nickel based alloys, Aerospace Industry

1. INTRODUCTION

Selective Laser Melting (SLM) is an additive manufacturing technology that is both applied for the production of metal prototypes and with increasing frequency applied to end-use products. A considerable demand for end use applications is generated by the aerospace industry. Here the applications of metals vary from non-structural components to complex flight critical hardware. This industry targets SLM technology in order to benefit from advantages such as weight reduction, functional integration, and reduced lead times. A frequently used material category is nickel based super alloys. These high performance alloys are used in some of the harshest engineering applications. The term covers a wide assortment of chemical compositions using a variety of alloying elements such as chromium, cobalt, niobium, molybdenum, tungsten, tantalum, and titanium. Depending on the composition the primary strengthening mechanisms come from a combination of solid solution strengthening, precipitation hardening, as well as work hardening. Nickel super alloys are known for their excellent corrosion resistance in oxidizing, reducing, and/or blanching conditions. Another highly desirable trait is their ability to withstand high service temperatures for prolonged periods of time, while still retaining high strength. Due to their excellent thermal, mechanical, and chemical resistant properties – these are the most commonly used alloys in aircraft turbine components. In addition, they are commonly found in nuclear reactors as well as petrochemical applications. Only a subset of these nickel super alloys have been widely characterized in literature. Of those characterized Inconel 625 has been investigated by Hack et al. and Helvajian et al. Choi et al. have studied the densification behaviour and microstructural development of Inconel 718. Finally of the more popular alloys ASTM has published additive manufacturing standards for Inconel 625 and 718.

SLM is in many respects fundamentally an iterative laser-based welding process, thus parameterization considers typical welding parameters and constraints. Some of the key factors that contribute to a stable process and result in high density components are layer thickness, process space temperature, laser spot diameter, laser power, scan speed. Of these most can be programmed independently and therefore a large optimization domain exists. This paper discusses existing approaches for determining process parameters and then an approach using a predictive software tool to eliminate the material, time, and engineering knowledge associated with the former. This software tool is validated in two material alloy systems and benchmarked on a third based against existing literature. Additionally, it will be demonstrated how using the proposed software tools allow not only singular parameter development, but multiple variations that can be based on factors such as changing powder size distributions resulting from recycling or different suppliers.

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2. PARAMETER DEVELOPMENT

Parameter development is the fundamental science of all SLM applications. Before it is possible to produce prototypes or end-use production components with metal additive manufacturing it is first essential to derive or arrive at stable processing conditions. The definition of stable processing conditions has a few key notes that should be pointed out. Gibson et al. Describe the fundamentals of SLM and note it is critical that a stable process fully solidifies the current layer of powder. Morgan et al. evaluated the impact of processing conditions and noted the positive impacts towards the higher degree of melting. Bauer et al. (2015) observed that excess of weld spatter and welding fumes is a critical failure mode for the durational sustainability of part production, the consistency of the energy source transmission, and critical for the replenishment of feedstock material in the next iteration step.

2.1 Existing Approaches

Engineers, researchers, and scientists take many approaches to converge on suitable processing conditions. Bauer et al. demonstrate the use of a full factorial parameter study to converge on settings that yield the highest density components. Clymer et al. identify the process mapping problem as multi-objective and use a bounded-objective function method which optimizes a single objective while using the other objectives to form additional constraints. Kasperovich et al. use a One Factor at a Time Approach (OFAT) to straightforwardly identify a relative optima for parameter combinations. Calignano et al. use a Taguchi L36 design to search for the optimal conditions for self-supporting additive components and Aboutaleb et al. demonstrate the use of an efficient multi-objective process optimization framework to optimize the quality of parts produced with SLM. Their framework decomposes a master multi-objective optimization problem down into a sequence of single-objective sub-problems. The common theme for these approaches is they demonstrate a strong level of time, engineering knowledge, and test material.

3. PARAMETER CREATION VIA SOFTWARE APPROACH

The software based approach as provided by the AM OPTOMET tool eliminates many of the previously described methods for global and local process parameter domain exploration. AM OPTOMET requires key influencing factors such as machine capability, material composition, powder properties, spot diameter, and platform temperature.

3.1 Machine Definition

The machine definition describes the capabilities and constraints of the machine in order to perform the output process parameter calculation. Figure one describes the required inputs and the format for their entry.

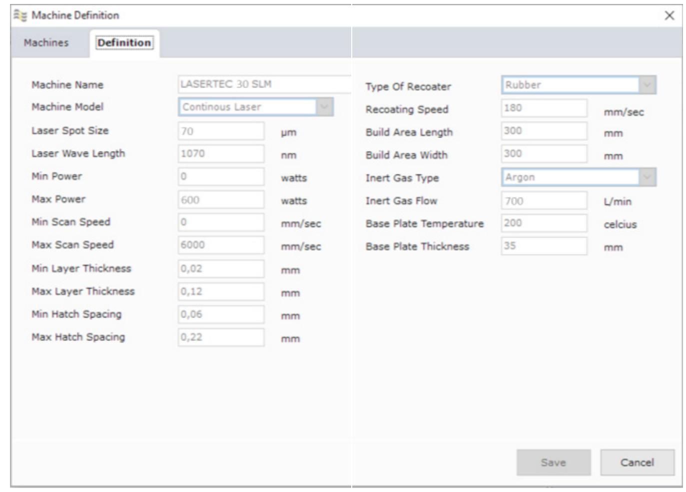

Fig. 1. Machine Definition

3.2 Material Composition

Alloy compositions differ slightly from producer to producer and from lot to lot. The software considers the impact of each base element by its share from the total composition. The basic version of the software tool allows the variation of composition weights within the provided known materials e.g. Inconel 625, AlSi10Mg. Within the advanced version of the software which was used for this paper, a user is able to select, with attention to physical constraints, new materials. With the advanced feature the algorithm will provide stable welding parameters. However, consideration is still advised to processability for additive and constraints such as back reflection, material absorptivity, and emissivity.

3.3 Powder Properties

A crucial element for the successful deposition and supply of thin powder layers with recoating elements is the particle distribution and flowability of powder materials. The distribution is described in material supplier certificate and data sheets. This statistic based definition describes D10, D50, and D90 values for powder lots. Also required is flowability metrics and then the software derives values such as the mean and peak values for the powder. These values have an impact on heat conductivity, surface roughness and the minimal printable layer thicknesses.

3.4 Spot Diameter

Minimum laser spot sizes differ based on the optics assembly. Therefore many commercial additive systems have varying spot sizes. Common spot sizes range from 35 µm to 100 µm. It is also possible for machines to have a variable range for the effective spot diameter. This option is especially useful for increasing the productivity of the SLM process. This additional variable can be accounted for in the AMOptoMet software tool.