

# Development of SLM quality system for gas turbines engines parts production

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**Abstract.** The work represents the approaches for designing the quality system for gas turbines engines parts additive manufacturing. For gas turbines engines applications, the quality parameters obtained by the selective laser melting are insufficient and require the subsequent surface treatment. To reduce the cost of additional manufacturing and improve the quality parameters, it is necessary to predict the surface structure that could be formed by selecting process parameters. The paper deals with each element of the selective laser melting technological process which effects on the manufactured part quality and suggests appropriate measures to achieve and maintain a high level of quality.

## 1. Introduction

Selective laser melting (SLM) is the powder bed fusion process, which are occurred at a high melting temperature. High local temperature gradients and briefly cooling cause the residual stresses and part deformations [1]. The consequences are additional surface treatment and reduced productivity.

To understand how to control the formation of the residual stresses and forms deformation, a reliable method is investigation of influences between the technological parameters and quality behaviours. There are some basic physics mechanisms of selective laser melting process they lead to part distortion and cracks: high temperature gradient, high viscosity and surface tension of molten powder zone, un-melting powder and oxidized particles [2].

The following variables of SLM process can be established [3,4]:

- Powder, composition, size distribution, shape, thickness of melting layer;
- Laser, power, spot size, beam spatial distribution, scanning velocity and protective gas atmosphere;
- Strategy of manufacturing

The main target of the research is to find and control the optimum SLM process parameters to minimize the roughness, residual stresses and part deformations. The SLM quality system for gas turbines engines parts production is based on interaction model of the technological factors affecting the quality of fabricated parts.

There are many methods for predicting the temperature distribution and residual stress during SLM process. These methods can be classified into three groups. The first group is the simulation method [5]. The second group is the researches which focus on the experimental works. The last group is the

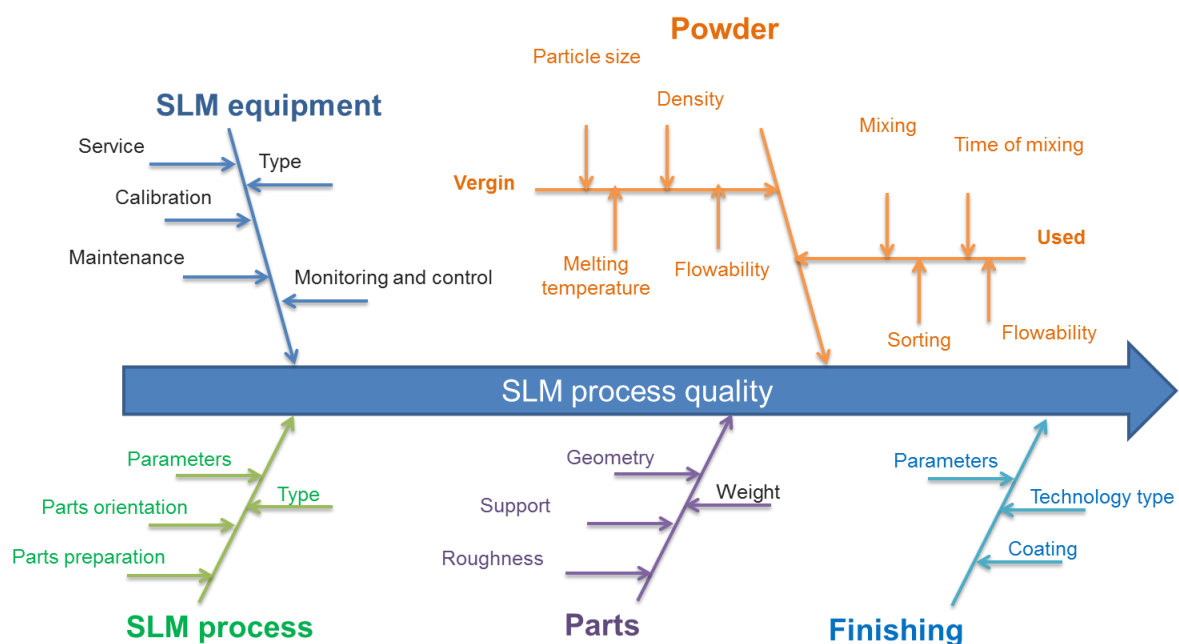


comparison of simulation and experimental results [6]. It is difficult to predict part distortion due to enormous computational layer analysis. Li et al. proposed to divide a SLM process for a practical part into three scales such as micro scale, meso scale and macro scale [7]. With this approach, the temperature history and residual stress fields during the SLM process were predicted. Thermal information has been transferred through micro scale laser scanning, meso scale layer hatching, and macro scale part build-up [8].

## 2. Description of the model

We developed the model of influences of SLM process parameters on quality, Ishikawa diagram.

The quality of the final part is decided by powder properties, process parameters, SLM equipment characteristics, finishing and detail behaviours as shown in Figure 1.



**Figure 1.** Ishikawa diagram of SLM process quality.

SLM equipment characteristics are determined by type of printers, monitoring system, kind of technologies, frequencies of service and maintenance. In order to ensure the technological accuracy it is recommended to calibrate production system and built every month test samples as benchmark of complex shape. Then it is necessary to check weight (density), dimensions, tolerances, and surface roughness under different parts orientation. The quality maintenance requires keeping the equipment daybook, where all actions are recognised: powder changing, cleaning, stopping, optic system controlling, parts replacement [9].

The specific behaviour of the molten material depends on the building conditions, where the temperature distribution in the meltpool is important for instance intermetallic phases, oxides, carbides, sulphides etc. The local cooling gradients and rates, which are dependent on the set of the main building parameters laser power and scan speed drive the microstructure formation and precipitation behaviour.

The investigating the quality of virgin powder is a first step of material controlling for achieving acceptable accuracy of part distortion and residual. Powder analyse previous to every manufacturing process regarding particle size distribution and particle shape using scanning electron microscope. Furthermore, it is necessary to evaluation powder flowability and apparent density [10]. The SLM

quality system should include the registration the qualitative and quantitative parameters of powders especially the proportion of mixed powders. In addition, the main material quality parameter is a rate of sieved and reused in a subsequent process powder.

It is clear that the part quality is dependent from SLM process parameters, which should be controlled and managed. In order to determine the optimal built parameters with an aspired objectives and technical requirements there is a need to consider many factors, such as cost, time, part quality, batch quantity together. For simplicity this task we developed a data base of SLM technological parameters for domestic powders: aluminium, titanium, heat resistant, stainless steel. We realised this data base in PDM system Teamcenter Manufacturing. The input technological parameters wish influence on part quality: scan speed and laser power, the layer thickness, the hatching distance, the hatching angle.

A list of corresponding minimal technological data to be controlled and stored is specified in Table 1.

**Table 1.** The quality ensuring activities

Quality parameters	Challenges
Input/output powder	Atmosphere controlled, optical inspection
Accuracy	Deviation prediction model, layer thickness
Surface	Post treatment, part orientation

The process of predicting and controlling the building parameters for part quality ensuring is promising method for manufacturing cost decreasing such expensive and poor machinability powder like titanium.

### 3. Development of SLM quality system

In this study, an effort to better understand the factors influencing on the part quality an evaluation method was applied.

Technological parameters were divided into two types: controlled by operator of additive machine (input) and defined by parts functional use (limiting conditions).

The input parameters:

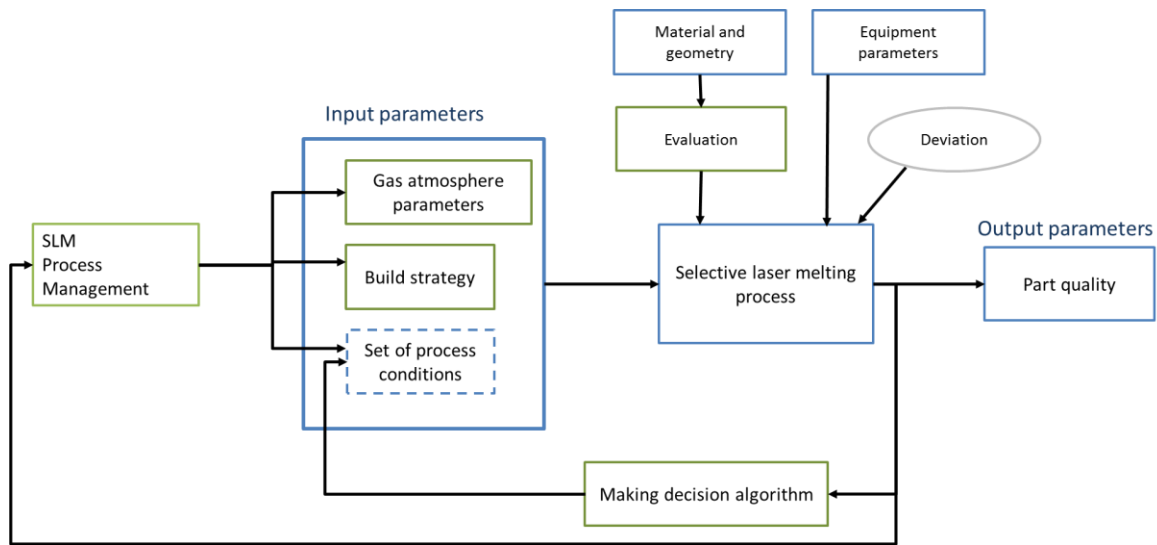
- gas atmosphere concentration (percentage of oxygen);
- layer thickness;
- set of process conditions: scan speed, laser power, hatching.

The limiting conditions: powder behaviours, geometry accuracy, grain size.

The input parameters influence on a SLM process, the layer thickness increasing effort on bed fusion and density of melting material is decreasing. Another example, if we increase the oxygen concentration in the building camera a melting material becomes more crack-sensitive.

We propose to use the SLM quality system which is based on managing and controlling of input parameters taking into account the limiting conditions.

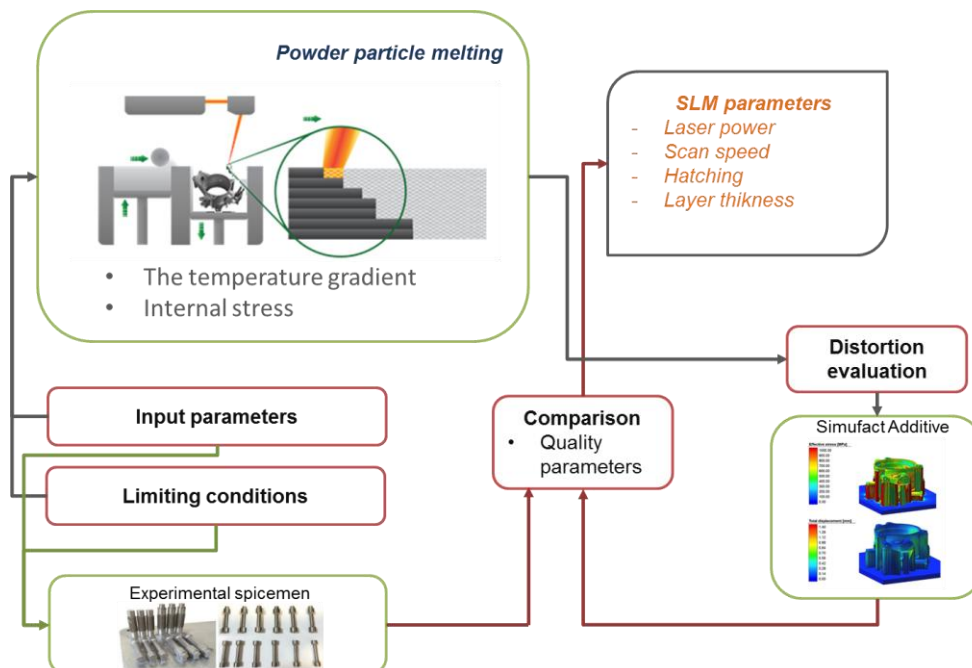
The main blocks of the SLM quality system is shown in Figure 2. In order to select the appropriate set of technological parameters the system uses a making decision algorithm, selection of input parameters depend on the link between part requirements (accuracy, geometry, surface) and building regimes for corresponding material and mechanical behaviors. The main idea of this system, is that decision and denoting of SLM parameters are based on experience, statistic database included in making decision algorithm. After each successfully building the data base records input parameters by certain limiting conditions. Successfully is mean that all quality requires are satisfied.



**Figure 2.** The SLM quality system.

The making decision algorithm should include not only statistic database, but a method of quality prediction. The prediction of accuracy and surfaces behaviors found on physical process during SLM: temperature gradient and distortion, internal stress and deformations. For this approach we need monitoring SLM process and have ability to manage this process. Such system is the step to digital manufacturing transformation according the Industry 4.0 concept.

The Figure 3 demonstrates the developed perspective SLM quality system. It should be noted that we need the simulation model of SLM process for better understanding the link between input and output parameters under different limiting conditions.



**Figure 3.** The perspective SLM quality system.

Simulation methods have been widely used to predict residual stress and part distortion of the SLM processes. But it is only suitable for analyzing the thermal-mechanical model to predict residual stress and distortion of sintered specimen [11]. For original SLM part, it is difficult to predict part distortion due to requiring millions of micro-scale laser scans which will increase the computational ability of the computer hardware. We suggest using MSC Software Additive Simufact and compare numerical and experimental results.

A multi scale approach is highly needed to achieve acceptable accuracy of part distortion and internal stress. Li et al. proposed to divide a SLM process for a practical part into three scales such as micro scale, meso scale and macro scale [11]. With this approach, the temperature history and residual stress fields during the SLM process were predicted. Thermal information has been transferred through micro scale laser scanning, meso scale layer hatching, and macro scale part build-up.

The aim of this research is to develop a perspective quality system for SLM process based on making decision algorithm and predicting the part quality by SLM process simulation in consideration of the temperature distribution and internal stress in the workpiece. For carrying out the system, concept model for SLM quality system was established.

#### 4. Conclusion

We developed the model of influences of SLM process parameters on quality and built Ishikawa diagram. The SLM quality system includes technical-organizational method of managing and controlling SLM process.

For getting the requirement part quality influence factors must be considered such as limiting conditions (material properties, equipment specifications), input parameters (building conditions and process parameters) [10]. However, during SLM process, the localized compression and tension caused by the large temperature gradients and fast cooling will increase that lead to the significant internal stresses in workpiece and shape deformation.

Further study concern of investigation the influences of physical SLM parameters on part quality and development mathematical model of part melting according with requirement part quality.

#### References

- [1] Popovich A, Sufiiarov V 2016 Metal Powder Additive Manufacturing. Chapter: **10** *New Trends in 3D Printing. InTech*. 215–236
- [2] Manfred Schmid, Gideon Levy 2012 Quality Management and Estimation of Quality Costs for Additive Manufacturing with SLS *Fraunhofer Direct Digital Manufacturing Conference*
- [3] Sufiiarov V Sh, Popovich A A, Borisov E V, Polozov I A, Masaylo D V, Orlov A V 2017 The Effect of Layer Thickness at Selective Laser Melting *Procedia Engineering* **174** 126-134
- [4] Grigoriev A, Polozov I, Sufiiarov V, Popovich A 2017 In-situ synthesis of Ti2AlNb-based intermetallic alloy by selective laser melting *Journal of Alloys and Compounds* **704** 434-442
- [5] Tom Craeghs, Stijn Clijsters, Evren Yasa, Jean-Pierre Kruth Online quality control of selective laser melting *Proceedings of the 20th Solid Freeform Fabrication (SFF) symposium, Austin (Texas)*, **8-10** 212-226.
- [6] Agapovichev A V, Sotov A V, Kokareva V V, Smelov V G, Kyarimov R R 2017 Study of the structure and mechanical characteristics of samples obtained by selective laser melting technology from VT6 alloy metal powder *International Journal of Nanomechanics Science and Technology* **8(4)** 323-330
- [7] Li C, Liu J F and Guo Y B 2016 Efficient multiscale prediction of cantilever distortion by selective laser melting Annual *International Solid Freeform Fabrication Symposium*
- [8] Smelov V G, Sotov A V, Agapovichev A V 2016 Research on the possibility of restoring blades while repairing gas turbine engines parts by selective laser melting *IOP Conf. Series: Materials Science and Engineering* **140**

- [9] Agapovichev A V, Balaykin A V, Smelov V G 2015 Production technology of the internal combustion engine crankcase using additive technologies *Modern Applied Science* **9** 335-343
- [10] Park H. S, Tran N H, Nguyen D S 2017 Development of a predictive system for SLM product quality *IOP Publishing IOP Conf. Series: Materials Science and Engineering* **227**
- [11] Li C, Fu C H, Guo Y B 2016 A multiscale modeling approach for fast prediction of part distortion in selective laser melting *J Materials Processing Technology* **229** 703
- [12]