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# Metal based additive layer manufacturing: variations, correlations and process control

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**Abstract**

Additive layer manufacturing is emerging as the next generation in part manufacture. It is being adopted by aerospace, tool making, dental and medical industries to produce and develop new conceptual designs and products due to its speed and flexibility.
It has been noted that parts produced using additive layer manufacturing are not to a consistent quality. Variations have been recorded showing inadequate control over dimensional tolerances, surface roughness, porosity, and other defects in built parts. It is, however, possible to control these variables using real-time processes that currently lack adequate process measurement methods. This paper identifies process variation and lists parameters currently being recorded during a commercial additive manufacture (AM) machine build process. Furthermore, it examines correlations between manufactured parts and real time build variations.


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*Keywords:* Additive layer manufacturing; Variations; Process control; Correlations

## 1. Introduction

Product quality is a critical consideration when producing any product for commercial use. Quality is the main driver that directly influences customer satisfaction, which in turn drives success in a competitive market[1]. Quality can be measured in many different ways; performance, reliability, durability, serviceability, aesthetics and conformance to standards; depending on the product one or more of these measures may be more appropriate. To achieve any of these critical qualities in a product, manufacturing control has to be optimised. Currently, metal based additive layer manufacture (ALM) has been utilised to produce parts for aerospace, tool making, dental and medical


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industries[2]. Originally, the adoption of additive layer manufacturing was to provide designers with time efficient access to prototype parts. Engineers and manufacturers soon realised that ALM could offer a faster route to market if the products that the process produced could be consistently manufactured to industry standards.

Currently there is a body of research being aimed at process control in regards to metal based additive layer manufacture[3,4] These papers consider the enactment of the process citing the need for extra sensors integrated into existing AM machines to improve manufacturing quality. There are a number of suggested approaches, including the use of in-process cameras that capture; the layer quality[5,6,7,8,9], melt shape[10,11,12,13] and melt temperature[14,15,16,17]. There are also researchers considering process quality evaluations relating to temperature change within the build chamber. At present no work has been reported looking at the overall number of variations in the build process.

This paper will aim to identify all of the variables that occur within the undertaking of an AM process using in-process control parameters that are applied by the machine operator. The sensor logs are normally hidden from machine operators, but have been made accessible for this research by the machine manufacturer. It is currently assumed that the levels set for these parameters and variations experienced during a process will contribute to dimensional inaccuracies, feature errors, porosity, layer delamination, curling and poor material properties. It is not known how variations in and potentially interactions between these parameters may be linked to process quality. In part, this is because the process parameter settings are chosen on a trial-and-error basis[4]. However, there is a clear need to investigate the information held in relation to the enactment of a particular process in order to determine the required levels of process control. Future research can then explore potential process optimisation.

The key element of work to be reported here is an initial assessment of the information held within the process log data. This will include the nature of the data associated with each variable and the level of information that can be extracted, either from individual data streams or more holistically by considering several variables together. This in turn will require consideration of suitable data processing tools and the application of knowledge based analysis approaches, with a view to enabling wider consideration of how research currently being conducted within the sector can be applied.

This paper will firstly introduce the powder bed fusion process. It will then go on to outline the process variables before describing how these variables are recorded within the build log. The aim of the work is to engineer a knowledge based solution that will enable better process control by using the information contained in the log.

## 2. Powder Bed Fusion Process

Selective laser melting (SLM) utilises a laser to provide energy to a metallic raw material. Figure 1 shows the build chamber of an AM250 selective laser melt (SLM) machine.

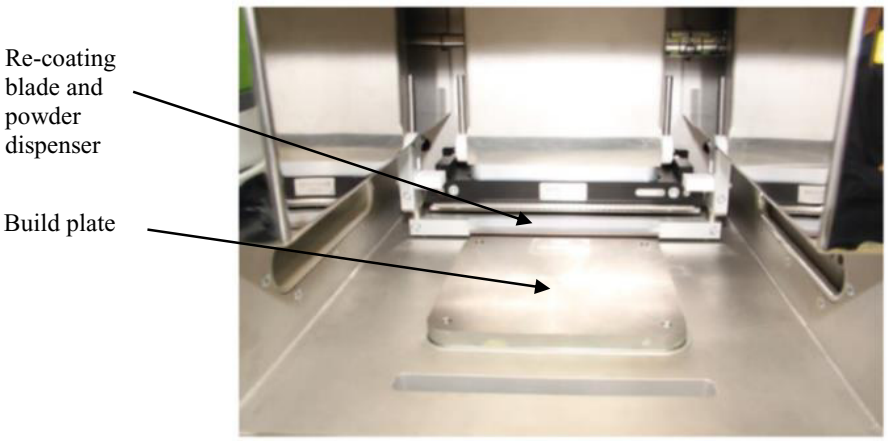


Fig. 1. Renishaw AM250 Build Chamber