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Powder coater monitoring for detection of anomalies in DMLM process

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Abstract

Additive Manufacturing (AM) is becoming more and more favorable in aerospace industry applications. However, the quality standards for this type of applications are very high, therefore a thorough investigation is required not only after manufacturing but also during the AM process. The tool introduced in this study visually demonstrates if there are any anomalies during powder coating in Direct Metal Laser Melting (DMLM) process. This tool is based on an algorithm that collects and analyzes the images of powder coating and determines whether the powder was spread evenly, or an anomaly occurred during coating. In this study, also a cross validation was carried out with the AM distortion simulation results of the corresponding test part. The same layers where an anomaly was detected in the powder coating analysis tool were investigated in the simulation results and a slight indication was observed, and that validates the outcome of the tool. This study demonstrates results of process anomalies observed in a test part build.

1. Introduction

According to the definition of American Society of Testing and Materials (ASTM) standard F2792, additive manufacturing (AM) is defined as "combining or joining raw materials to make objects from 3D model data in layer-by-layer manner as opposed to conventional subtractive methods" [1]. Direct Metal Laser Melting (DMLM), one of the AM methods using metal materials, is a process that stands out with its promising capabilities while also it is one of the most preferred and widely used processes among AM methods [2]. In a typical DMLM process, a laser beam used as the energy source selectively scans across a defined thin layer (which also creates layer thickness) on the powder bed formed by the laying of metal powders with a powder recoater blade. During scanning, the laser melts the metal powders to a level that fuses them with the previous layer. This process continues by depositing the layers on top of each other until the desired 3D geometry is achieved [3]. Considering the advantageous aspects of AM against conventional subtractive manufacturing methods, it becomes more and more important to choose the suitable manufacturing method for critical parts used in various industries. However, accuracy and precision studies are of great importance to establish quality standards for the AM process and to capture the sustainability of the process [4]. Especially in the aviation industry, quality for high-value applications where component failure could result in major financial losses, cannot be tolerated, and needs improvement. Advances in process control, with the use of data during manufacturing, have allowed AM techniques to be improved significantly [5]. Therefore, monitoring the manufacturing process and analyzing the data collected from it will greatly benefit AM engineers in better understanding and development of the process. Build errors that may occur during the DMLM process can cause the functional requirements and geometric tolerances expected from the part not to be met, which can cause cost and time loss.

Due to this need in the process, an analysis tool that uses image analysis algorithms has been developed in order to collect raw in-situ image data and post-build analysis of it to use them as outputs in order to meet quality requirements. Tracking whether there is an anomaly in the previous layers or whether the powder recoater blade was able to spread the powder homogeneously at the desired thickness provides a great advantage in understanding the quality of the parts manufactured.

2.Experimental and Simulation Methods

2.1. DMLM Experiment

In this study, CoCrMo metal alloy powders with spherical morphology are used. The powder is produced via gas atomization method and it's supplied from Praxair company. Table 1 shows the chemical analysis of the powder. It is critical to mention that the amount of the minor elements (< 1 wt.%) such as Aluminum, Boron, Carbon and Iron is 1.59 wt.% in total. The test parts were manufactured by Concept Laser M2 machine. The standard vendor process parameters were used in the production of the test part.

Table 1. Chemical analysis of CoCrMo metal alloy powder.

Element	Wt. %
Cobalt	64.91
Chromium	27.68
Molybdenum	5.82
Minor elements	1.59

2.2. Powder Coating Analysis – Processed Images

With the tool introduced in this study, a post-build image system has been developed that analyzes the build chamber images collected by the optical camera during the process in the AM machine. Figure 1 shows a schematic of DMLM process build chamber with powder coating monitoring system. The tool detects the anomalies caused by the interactions between the powder bed and the powder recoater blade. Embedded optical camera takes two images of the DMLM process, one before recoating the layer and one after the powder is recoated and the laser melting. These collected images become inputs for this powder coating analysis tool. After completion of build, generated raw images are converted into gray-scale images by the tool before the analysis starts. Definition of bounding box as the unique image calibration file for the build chamber is another input for the tool. Other inputs for the tool are related to the process itself, powder material, layer thickness etc. This analysis methodology is a combination of several image analysis tools to analyze recoat images for anomalies in every layer.

The tool can detect and classify anomaly types like short feed, part exposure, recoater blade contacts and chatters. Short feed occurs when there is not sufficient powder available to cover entire build plate. Part exposure takes place after recoating the powder and if the part is exposed above the powder from previous layer. If recoater blade contacts and hits the exposed part, tool can label this anomaly type as recoater contact detection. Also, if recoater blade bounces on the surface while laying powder due to self-vibration mechanism generation, this phenomenon is called as chatter. This tool generates a report that provides information about anomalies that have occurred during the process and generates point clouds to enable visualization of them within the part.

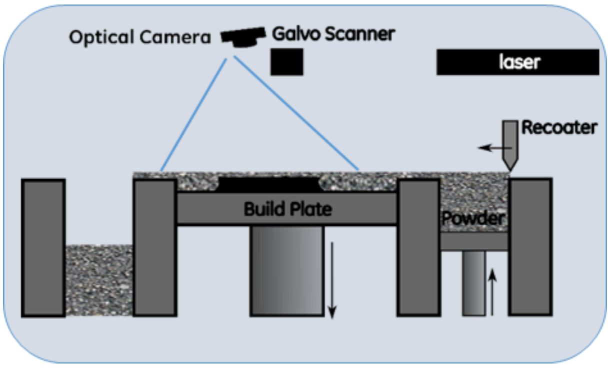

Fig 1. Schematic representation of DMLM process.

In Figure 2, flowchart for data gathering and management is presented.

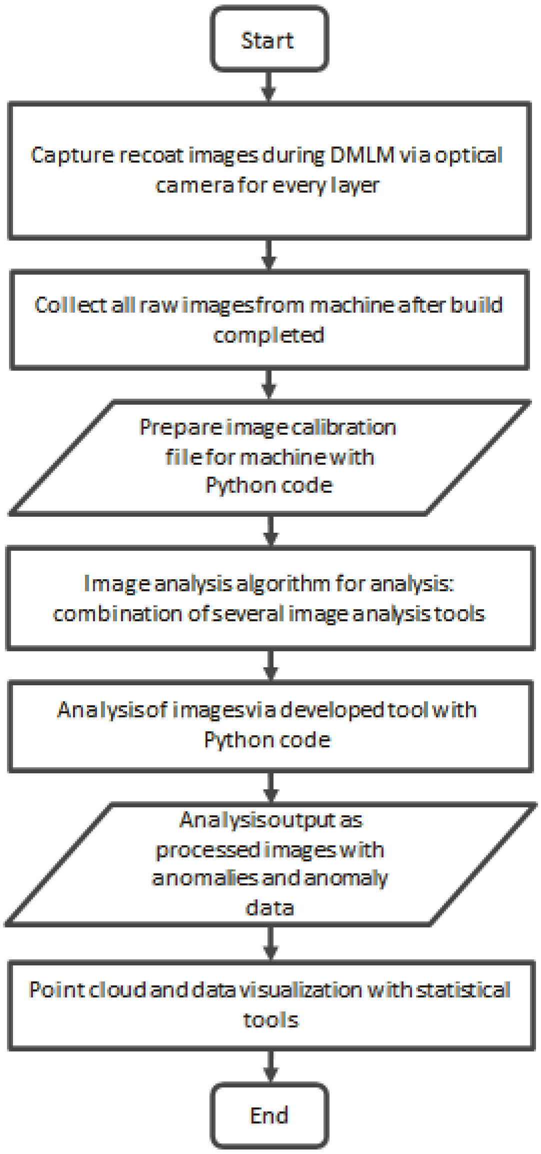

Fig 2. Flowchart showing how the tool works.

This tool helps AM design engineers and quality engineers improve current manufacturing system to a more reliable system and produce aviation quality outputs.

2.3. Simulation

Fast and accurate simulation of metal parts manufactured with AM is an important and useful methodology to ensure manufacturability and to check potential errors that may occur [6]. Thermomechanical analysis is performed on the computational domain to simulate the construction process. Finally, it is intended to validate the AM numerical simulation using experimental data [7].

For the thermomechanical numerical analysis, commercial software Simufact Additive 4.1 was utilized. The build plate was selected as 316L steel plate as it was in the production with dimension of 245x245x50 mm. Build plate and build structures were discretized with voxel mesh elements. For the build plate, it was decided to use 3 mm mesh size and 1 mm for the build part structures. The total number of the voxel elements and nodes were 1609720 and 209954, respectively. The element sizes were defined according to the convergence and computational cost studies.

3. Results and discussion

Overhangs are critical DMLM features that must be considered during part design and manufacturing. They affect the final quality of the part. These structures become the main concerns for design engineers especially in terms of geometric accuracy and surface roughness. Contrary to structures that benefit from being contacted to previous layers and thus are called self-supporting geometries, overhang geometries (also called downward facing surfaces) suffer from lack of support and are susceptible to distortion during the build process [8 - 10].

Demonstrations of the processed image outputs given by the tool with the working principle are shown in Figures 3 and 4. As seen in Figure 3, downfacing surfaces with no support structure underneath are shown as overhang regions. These regions have been displaced according to the desired design, with the accumulated heat input in the region within melt pool onto the previous layers. The developed analysis tool detected and labeled these regions in the powder bed. In that figure, metal surfaces that are exposed from the previous layers first appear. The analysis tool marked this image in pink color with intensity change values and the edge detection algorithms it used to mark these defects. Finally, after laser hitting this layer, it is shown where the marked anomaly locations coincide in the last layer in turquoise color. The purpose here is to determine the exact location of the anomaly on the part or on the support.

The detected anomaly in Figure 4 is similar to the overhang anomaly region shown in previous figure. This one occurs in a higher layer number, meaning a higher z-height. Here, the region is the connection of two features. Again, the related region was marked in turquoise color. At the connection point there is no bulk material underneath to support the feature, so it causes a disruption in the powder coating process, although it is a minor one in this case.

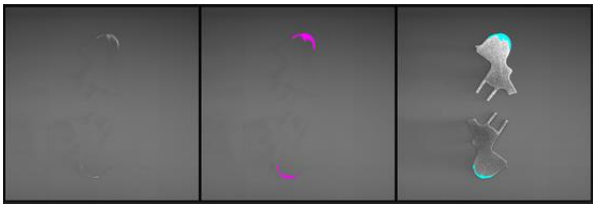

Fig 3. Detected anomalies in overhang region.

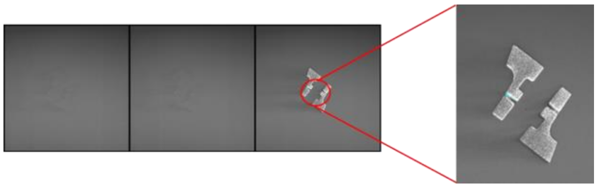

Fig 4. Detected anomalies in connection region of geometries.

In order to verify these anomaly regions detected with the tool, simulation results of this specific build were used. Build simulation parameters and tools used in this study were introduced in 2.3. This simulation methodology helps predict any anomalies before the DMLM build process. If a very large anomaly is detected by the simulation before the DMLM process, it is better to make modifications on the design or layout to avoid any potential build interruption.

The same layer height where the powder coating anomaly was observed was investigated in the simulation result. Figures 5 and 6 are showing the exact same simulation layers with the layers shown in Figures 3 and 4, respectively. Here the color map shows slightly larger displacement in AM-layer z-direction compared to previous layers. That demonstrates an indication in these regions where there was a powder coating issue detected by the tool. The detected anomaly by the tool in overhang region in Figure 3 matches with the predicted simulation result in Figure 5 for the same layer of the build. Similarly, the detected anomaly in the connection region of the test part in Figure 4 was predicted as a slightly larger displacement in AM-layer z-direction in Figure 6. It can be concluded that, the color marked regions of the tool fits the color map that was obtained from simulation results.

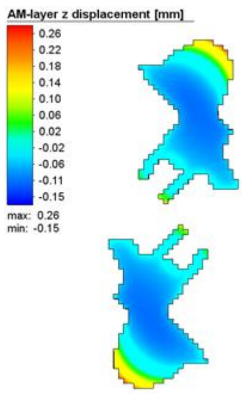

Fig 5. Simulation results overhang region.

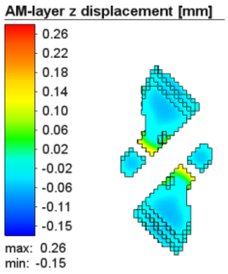

Fig 6. Simulation results in connection region of geometries.

The powder coating analysis reveals process anomalies during powder coating. Cross validation was done with the simulation results for the corresponding layers. Although these anomalies did not cause any flaw in this DMLM test part due to the robustness of the process, this powder coating analysis method is very beneficial for monitoring the process in detail.

4. Conclusions

In this study, a tool developed for the detection and visualization of anomalies caused by the interactions between the powder bed and the powder recoater blade during DMLM is presented. The tool analyzes the powder bed images collected by the optical camera inside the build chamber during production with image analysis algorithms and presents different types of anomalies as processed images. With this approach, the examination and interpretation of the anomalies that occur in the part are achieved. For cross validation, the results of the tool were compared with AM distortion simulation results. It was observed that the anomaly locations detected by the tool were also detected by the simulation. With this tool and the validation method, a beneficial information is obtained on monitoring process anomalies.

Acknowledgments

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