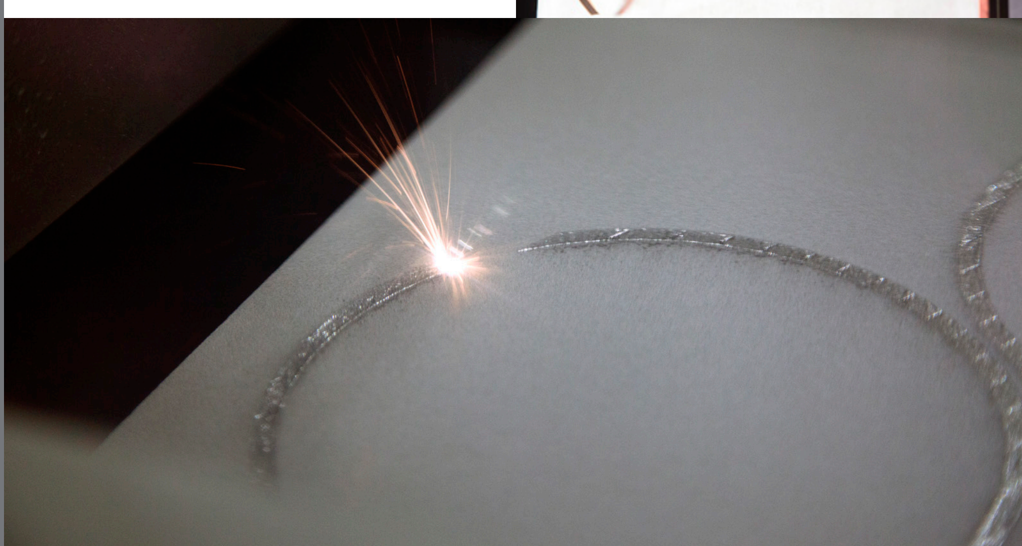
Stratasys Direct Manufacturing Performs Field Validation of VELO^{3D} Assure™

Assure provides industry-leading in-process quality assurance and control for Laser Powder Bed Fusion

By Andrew Carter, Sr Manufacturing Engineer

stratasys
DIRECT MANUFACTURING



Industry-leading in-process quality assurance and control

Stratasys Direct Manufacturing teamed with VELO3D to support a field test validation of VELO3D's newest product, Assure.

For twelve weeks, Stratasys Direct implemented Assure alongside their production process and performed an evaluation to corroborate findings generated by VELO3D.

Stratasys Direct has now integrated Assure to monitor the integrity of builds, substantiate bulk material density, observe ongoing process metrics, and verify the calibration of the system throughout ongoing production.

From prototyping to production

Additive manufacturing (AM) has been used for decades for prototyping and project work. Case studies show that AM can produce new geometries, accelerate development and save costs. But the movement to production has been slow.

AM can print parts and meet requirements for single units, but scaling from a single part into serial production has been challenging. OEMs lack confidence in AM process control, and AM users struggle to demonstrate it. Without visibility into each part's deposition lifetime AM becomes a risk.

The current process to qualify components for production requires an established material property database and actual product destructive testing. In-process quality measurements are the key to limiting the risk of reduced material property testing and costly component destructive testing, but as an industry we lack a clear solution to this challenge. Until now.

Assure

In Powder Bed Fusion, an additive manufacturing process, metal parts are printed, layer by layer, with lasers drawing a part's 2D cross-section. Each layer may feature millions of pixels or hatches, and each part is typically built from thousands of layers. This results in billions of data points – opportunities to introduce defects, but also opportunities, with the right metrology and software suite, to measure the quality of a build.

Assure, a revolutionary quality tracking system for the VELO3D Sapphire® printer, does just that. Assure provides an intuitive user interface to interpret vast amounts of multi-sensor real-time process data. This interface tracks tool health and provides an estimate of part quality increasing user confidence in deposited material density.

Understanding tool health

Assure tracks and reports Sapphire's 'pre-flight' check prior to each build, ensuring that parameters are within specification. Included in the pre-flight check, Sapphire automatically ensures the following:

- Beam size across the build plane
- Multi-laser overlay accuracy
- Optical window cleanliness
- Powder bed health
- Sensor calibration

During a build, the system validates that critical parameters such as powder bed health, consumables, chamber atmosphere, and optics stay in spec. Prior to each layer, Sapphire validates powder bed health, environmental conditions, and optics.

During each layer, the system tracks melt pool data to validate that the layer is within tolerances. Furthermore, after each layer, the system checks for any protrusions from the previous print. Altogether, these checks validate that the Sapphire printers start good, stay good and validates that parts have predictable, uniform properties regardless of the originating printer. This data is visible in real-time to the user with Assure and can be summarized in a report following each build.

Assure is now integrated into Stratasys Direct's quality-control workflow and has already produced highly actionable insights. The user interface, with its intuitive graphs and charts, enables their engineers to see and interpret the vast amount collected during the builds.

This information assists the Stratasys Direct team in verifying the quality of each build and quickly coming to a conclusion in the event of an issue. Assure helps Stratasys Direct reduce production variation, improve yields, and better understand the factors that lead to build-to-build and part-to-part additive manufacturing quality.

Calculating part quality

The end goal of any additive part quality tracking system is to support the manufacturing of parts that perform to specifications. The VELO^{3D} Sapphire tool uses real-time, physics-based excursion detection algorithms to form a prediction of bulk material properties for each part. To create the algorithm used in the assessment, VELO^{3D} engineers intentionally introduced defects into test parts to monitor their impact on thermal emission.

The defects were introduced by either reducing the argon gas flow, changing the focus of the laser, or introducing fluctuations in powder bed thickness. The three different defect modes were chosen to represent a variety of failures that can occur and impact part quality. During each experiment, control samples were also inserted to measure a consistent baseline. After each build, the samples were cut into 1-2mm sections by electrical discharge machining (EDM) in the X-Z orientation. The sections were imaged using a Nikon XT V 160 x-ray system to measure bulk porosity. Figure 1 shows example X-ray images of samples with and without intentional defectivity.

The end result is Assure's Porosity Prediction. By continually analyzing the melt pool data and correlating it with multiple production runs on multiple systems, engineers can generate a statistically significant representation of the part in real-time.

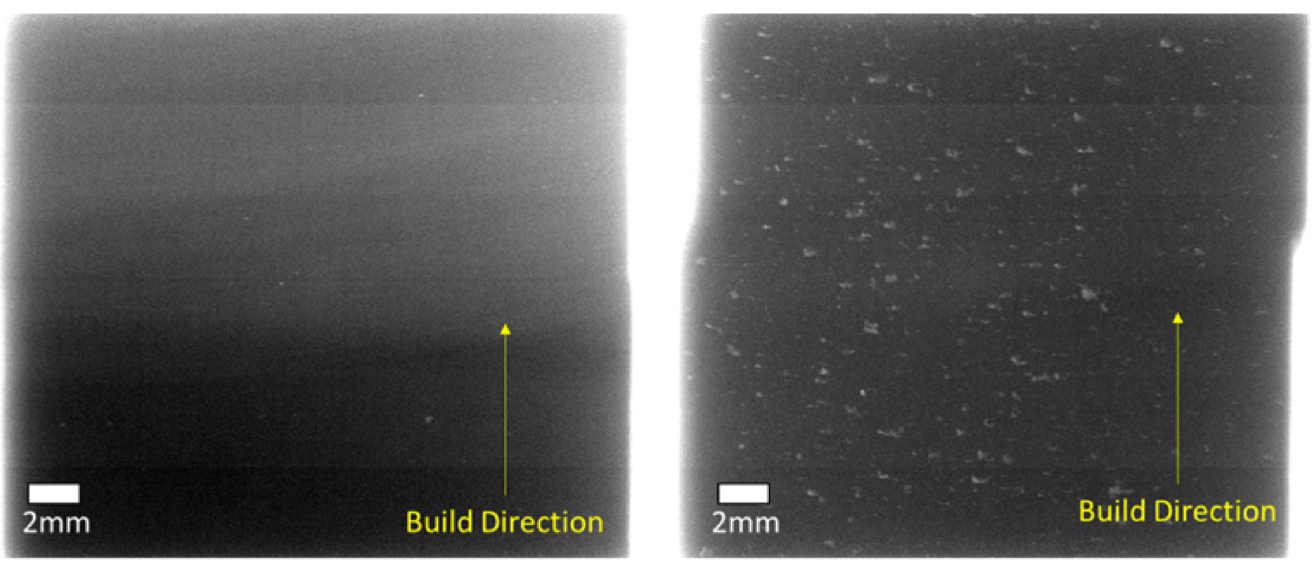


Figure 1: (Left) Representative x-ray image of a non-defective part showing minimal lack of fusion defects compared to (right) x-ray image of a defective part.

Field validation

Stratasys Direct Manufacturing collaborated with VELO3D engineers to validate Assure's performance in a production environment. During development, VELO3D used Assure to correlate system datasets to part performance. After generating an in-house dataset, VELO3D offered Assure to Stratasys Direct for in-depth evaluation and a field deployment. Jointly, the two companies gathered the data from these runs and evaluated the correlation of Assure predictions to the observed actual part performance.

To maintain an ongoing production schedule while still gathering data, VELO3D engineers generated a test structure to add to production builds run at Stratasys Direct. The test structure wedge (20mm x 41mm in width and length respectively) was designed to occupy a small area of the build plate so it could be integrated onto builds with minimal impact on customer parts.

These test structures 'stack' vertically creating a tower that varies in height to match the build z-height. Each validation build featured two test towers, one per laser, oriented with the base of the wedge facing the pump exhaust. These wedges were removed from the build plate and segmented from one another by hand. The sample geometry is shown in Figure 2 and is designed to allow for easy destructive testing. The test structure was merged onto several production builds at Stratasys Direct.

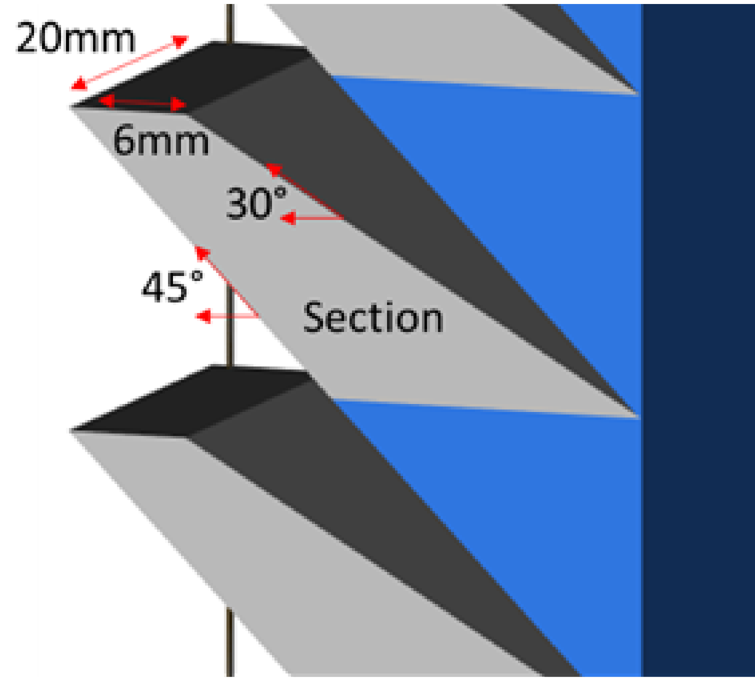


Figure 2: Test structure added to production builds to enable destructive testing.

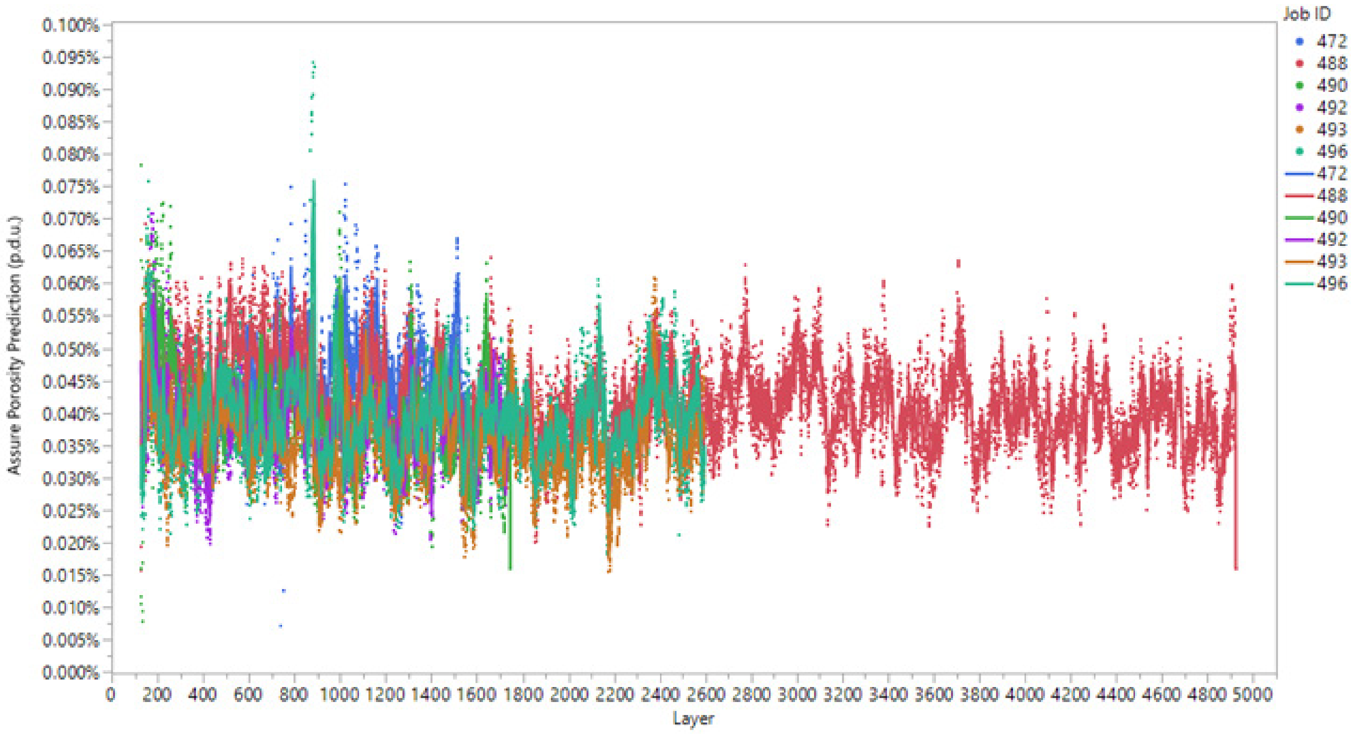


Figure 3: Assure porosity prediction by layer for test parts on production builds run at Stratasys Direct.

The Assure Porosity Prediction calculated from these initial builds is shown in Figure 3 for six production builds. It is apparent that the Assure predicted defectivity for these parts is relatively constant and low across all layers. The only deviation occurs for build 496 (aqua plot on Figure 3) on layer 865. Subsequent analysis of build interruptions indicated an emergency stop event at this layer which required a build restart.

The interrupt is clearly visible in the Assure Porosity Prediction data and indicates abnormal melt conditions. However, X-ray analysis of this part did not show any lack of fusion defects at this layer revealing that the melt conditions had not deviated enough to cause defectivity.

Overall, a total of 75 test structures were generated from these six production builds and analyzed by X-ray imaging. The results of the bulk porosity for these samples are shown in Figure 4. For actual porosity results, we utilize target metal properties as listed on the Sapphire Nickel 718 datasheet. The average bulk porosity level for all test structures was 0.02% with no single part exhibiting porosity higher than 0.1% (99.9% part density). These results indicate no significant deviations in print quality for these builds.

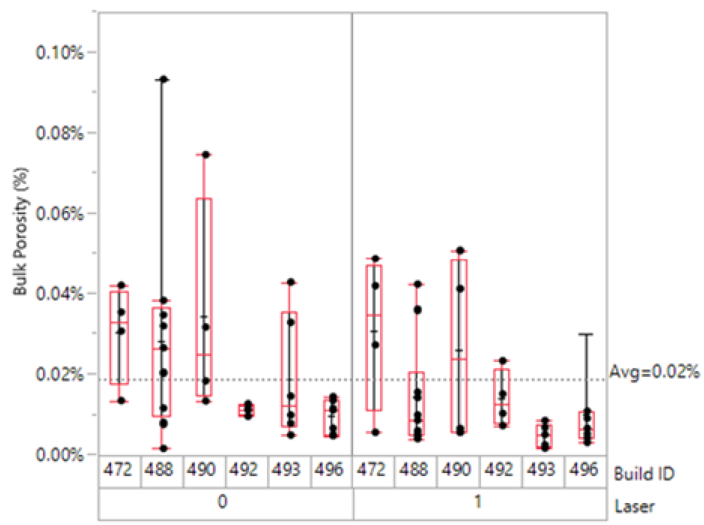


Figure 4: Bulk defectivity measured on test parts by x-ray imagery.

Inducing failures

The previous results from production runs on the Stratasys Direct system helped to create a solid baseline of data for low porosity, good quality parts. However, to observe the accuracy of Assure's prediction algorithm, the team also wanted to observe low-quality results. To do this, the team created a test that would attempt to induce defects in the build. The same test structure (Figure 2) was used in various locations on the build plate.

Engineers developed two test conditions: 1) vary argon gas flow and 2) vary laser beam spot size. The tests were run independently with control samples integrated prior to each test run.

The data gathered from the builds (Figure 5) was plotted in conjunction with the data generated during production runs at Stratasys Direct and test runs at VELO^{3D}. The plot shows a correlation between the Assure Porosity Prediction and Volume Porosity results and shows similar profiles between Stratasys Direct's production system and VELO^{3D}'s systems.

Under production conditions, Stratasys Direct's Sapphire tool yields very dense components (represented by the hollow blue squares). The adjustment in beam size at Stratasys Direct was not enough to introduce defects (resulting in the two solid blue data points in the low-to-no porosity region) while the adjustment in argon flow produced material well in the defective range (resulting in the two solid build data points in the high porosity range).

This implies that the Sapphire's process window for laser spot size is large. The data suggests a range where Porosity Prediction and measured Porosity concur with regard to high quality metal. Likewise, there is a range exhibiting a higher probability of porosity in the material.

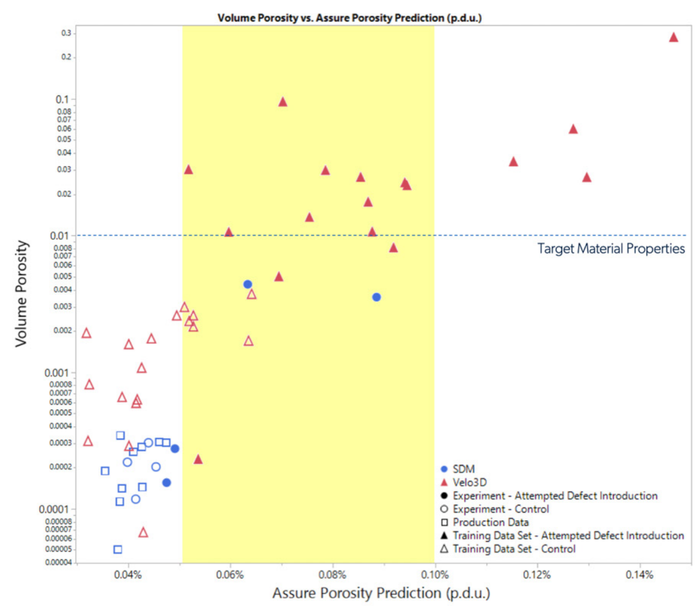


Figure 5: Log/linear graph of measured volume porosity (x-ray) vs. Assure porosity prediction for samples with intentionally generated defectivity and samples from production builds run at Stratasys Direct.

Future work

To fully utilize the Porosity Prediction as a go/no-go indicator of part quality, we would want to generate a four-quadrant graph with two axes: one representing actual volume porosity and one representing predicted porosity. Ideally, all data points above a target material properties line would show a prediction level higher than an established threshold. Likewise, all data points below this level would show a predicted level lower than an established threshold.

However, in real world results, we can see that while a correlation can be established, we cannot create a definite linear threshold value. Instead, on the left side of the graph, we observe low porosity and predict low porosity. For Assure Porosity Prediction values of below 0.05%, we see high quality parts. On the right side of the graph, we observe high porosity and predict high porosity.

So, for Assure Porosity Prediction values above 0.10%, we see low quality, porous parts. For values between 0.05% and 0.10% (the yellow zone indicated on the graph) further analysis is required.

Stratasys Direct's team and VELO3D will continue to work together to refine the algorithms used to process the sensor data with the intention of having a pass/fail metric of bulk material density. Over the next few quarters, we will refine the prediction to reduce the indeterminate region and broaden the scope to incorporate more geometric features.

	< 0.05%	**0.05% - 0.1**	**> 0.10%**
Porosity prediction	Predicted good part	Indeterminate	Predicted bad part

Figure 6: Assure porosity prediction levels and quality implications