SIGMA LABS

Quality Beyond Inspection™

PrintRite3D INSPECT®

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In-situ Melt pool "Thermal Signature" defect detection of recoater failure using co-Axial Planck Thermometry.

Prepared by

Scott Betts, R&D Process Engineer
Lars Jacquemetton, Senior Software Engineer

Approved by

Darren Beckett, CTO

Sigma Labs Inc.

3900 Paseo del Sol
Santa Fe, NM 87507

Introduction:

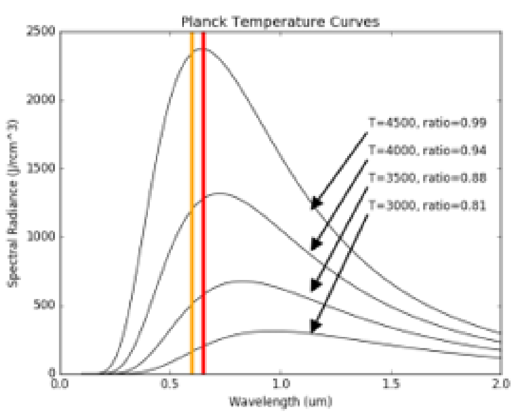
The drive to certify and qualify additively manufactured metal parts is heralding new methods of quality assurance that will ultimately allow AM end users to take the much needed "leap of faith" that is required to foster confidence in AM. Sigma labs has developed such a methodology that mines and digitalizes "thermal signatures" of the melt pool disturbances and respective discontinuities using emission spectroscopy. The evolution of thermal digital signature advances the digital thread that is much needed by certification and standard authorities.

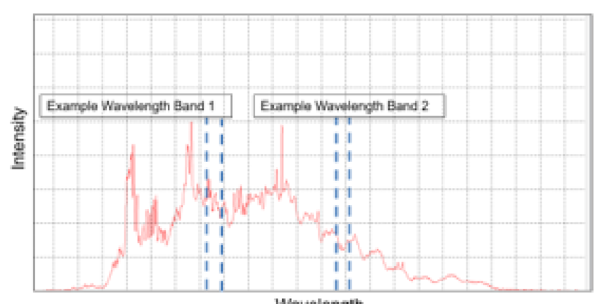
Producing a DMLS (direct metal laser sintered) part relies on controlling many input variables to get a high-quality finished part. For the most demanding applications like aerospace and defense, there is still uncharacterized variation in the process leading to expensive and lengthy post process part validation. Co-Axial Planck Thermometry provides a verified thermal signature in both in temperature and coordinates. Using this approach allows a deeper understanding of process variance whether that is layer-to-layer, part-to-part, build-to-build, or machine-to-machine.

Planck Thermometry Approach:

The curves in Figure 1 show radiated energy according to Planck's formula for an ideal black-body at increasing temperatures.

We sample this radiation at two wavelengths indicated by the vertical orange and red lines, and we cancel out various optical and emissivity effects by taking the ratio of the two values. This is the basis of the TEP™ (Thermal Energy Planck) and Relative Temperature metrics developed by Sigma Labs.





$$B_\nu[\nu,T] = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/k_BT}-1}$$

Figure 1: Planck Temperature Curve

Hardware:

To incorporate Co-Axial Planck Thermometry while maintaining Sigma Labs Inc. TED® metric, the radiated energy must be directed to each photodiode using a system of mirrors and lenses seen in Figure 2.

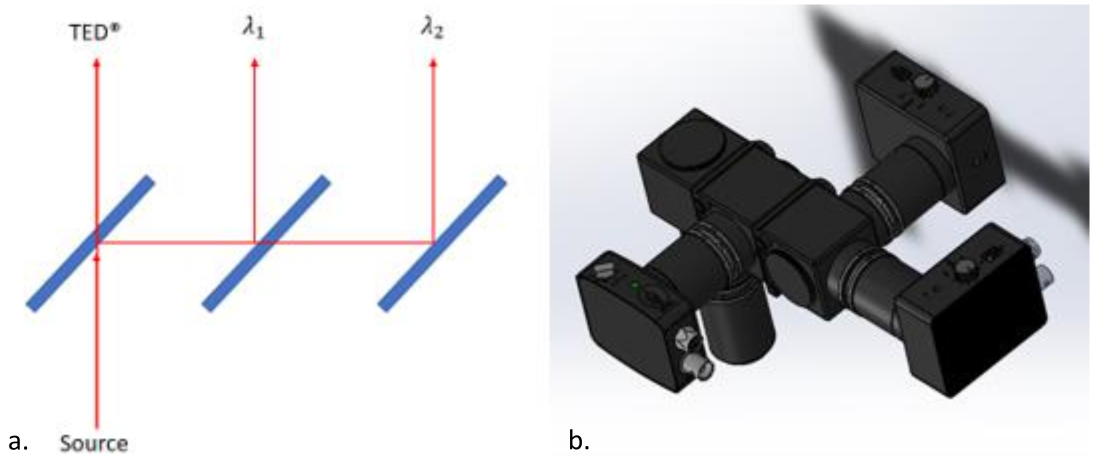


Figure 2: a, Co-Axial Planck Thermometry optics diagram. B, Mechanical design

Experimental Set Up:

All parts were built on an EOS M290 using Praxair 625 alloy. Using a geometry representative of a finned heat sink. All parts were built with the same nominal processing parameters.

Results:

The TEP™ (Thermal Energy Planck) metric is an excellent indicator of part failure. Figure 3a shows the powder bed image captured with the EOS camera system, 3b is the corresponding TEP™ scan viewer image showing little variance as expected for a part built nominally.

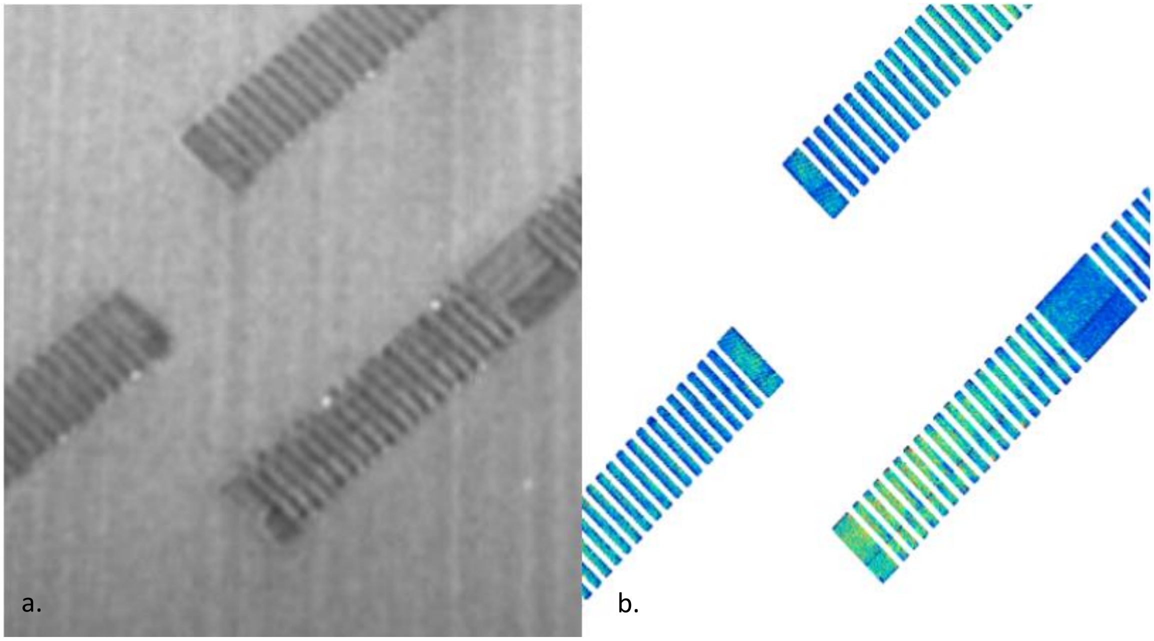


Figure 3: a. EOS powder bed image layer 50.   b, TEP™ Scan Viewer layer 50

As the build progressed the recoater blade began to contact the parts with increasing severity. Figure 4 shows the damage limited to certain fins. The corresponding TEP™ scan viewer signature correlates to this image with the damaged fins showing up with a higher TEP™ signature than neighboring parts.

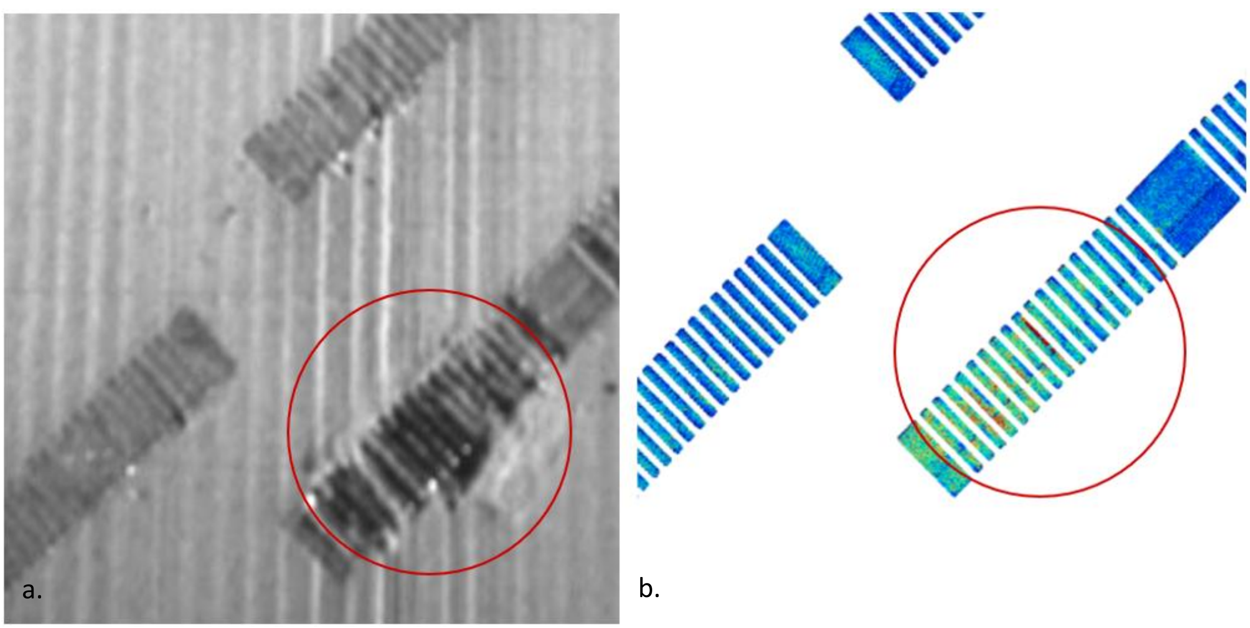


Figure 4: EOS powder bed image layer 314.   b, TEP™ Scan Viewer layer 314

Figure 5 is a further evaluation, this time using TEP™ Sigma, the standard deviation of TEP™. This allows the the visualization of the within part variance.

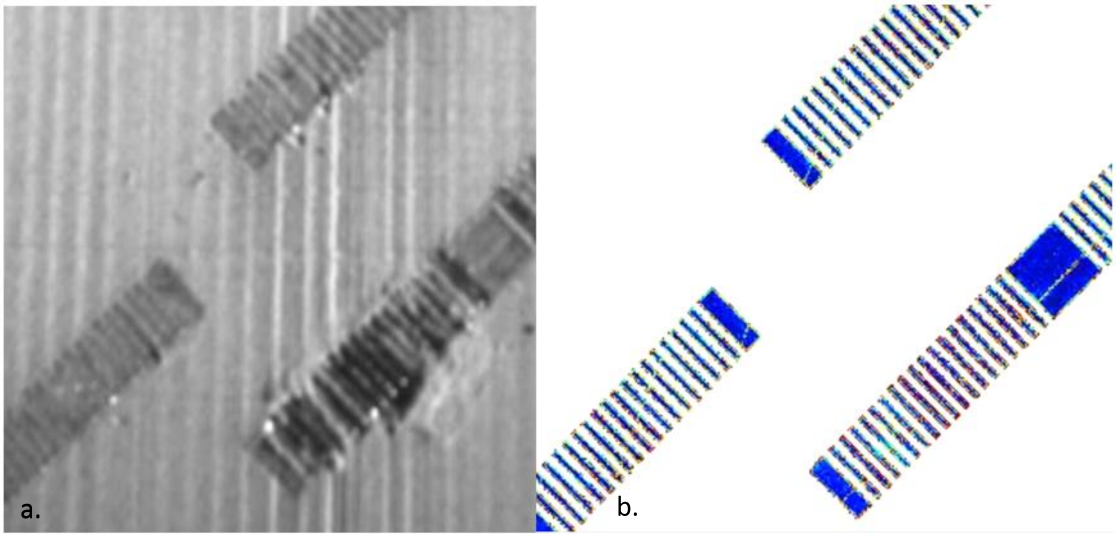


Figure 5: EOS powder bed image layer 314.   b, TEP™ Sigma Scan Viewer layer 314

Figure 6 shows the TEP™ Sigma SPC (statistical process control) chart for the failed heatsink per layer with powder bed images. The variance begins to increase at layer 225 becoming worse until total part failure occurs, this can be seen in the SPC chart before the powder bed images begin to show a disturbance. For future production builds the process engineer can change the upper and lower control limits to more easily show an out of control process and stop the part building or make a change prior to total failure.

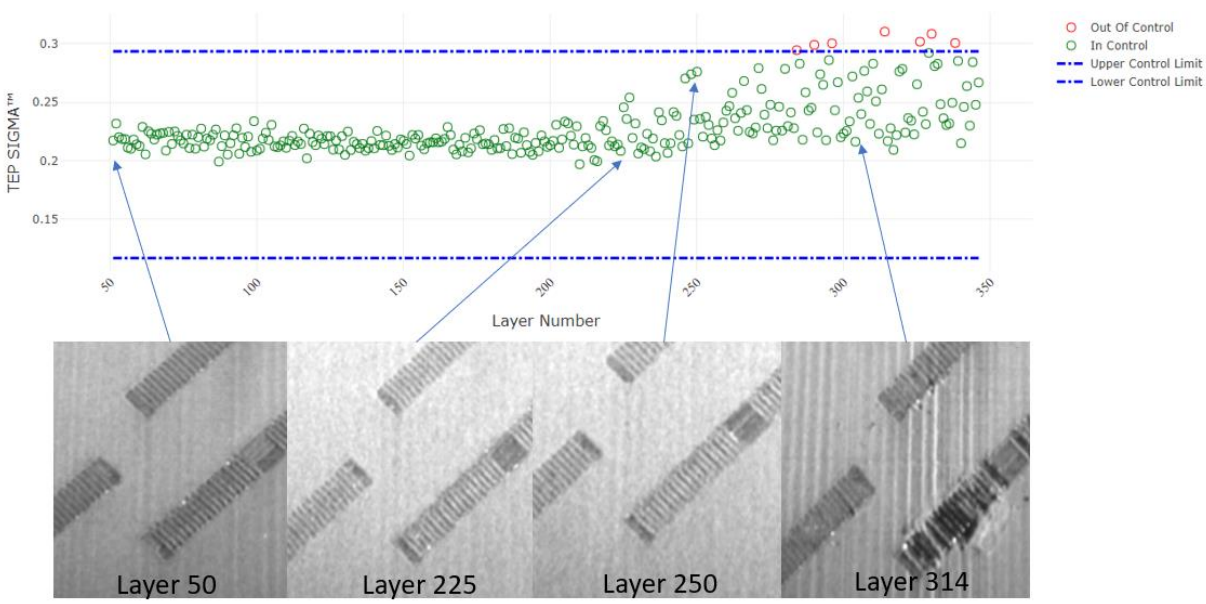


Figure 6: TEP Sigma SPC chart with EOS powder bed images.

Conclusions:

This experiment evaluated the sensitivity of the PrintRite3D INSPECT® software and Sigma's proprietary TEP™ and TEP™ Sigma IPQM® using co-axial Planck thermometry to identify disturbances from a failing part inducing recoater arm interaction.

Using Sigma's PrintRite3D INSPECT® software and proprietary algorithms that indirectly measure dependent in-process data captured from three photodetector signals, it was possible to infer the period in which the part defect first occurred using the SPC charts per part and per layer, potentially allowing for intervention before total part failure.