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In situ monitoring of the layer height in laser powder bed fusion

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Abstract

In situ process monitoring has frequently been cited as an critical requirement in certifying the performance of laser powder bed fusion (LPBF) components for use in high integrity applications. Despite much development in addressing this need, little attention has been been paid to monitoring the layer thickness during the process. In this paper, a laser displacement sensor has been integrated into the build chamber of an LPBF machine, and the height of the top surface layer of a component has been monitored during a build. This has permitted the deposited layer thickness to be measured throughout the build, and the effect on this of a change in processing conditions is characterised. The thermal contraction of the top layer in between successive laser scans has also been evaluated. This demonstrates the potential of utilising laser displacement sensory as a process monitoring tool in LPBF and provides insightful data for implementation in detailed process models.

KEYWORDS

selective laser melting, in situ testing, 316L steel

1 | INTRODUCTION

Despite significant and continuing research and development in laser powder bed fusion (LPBF) processes, the use of components in safety critical applications is still held back by a lack of confidence in their structural integrity. Certification ex situ presents a substantial challenge, given the huge range of process variables, which may influence the final part. As a result, a number of prominent reviews have identified in situ monitoring tools as being essential in the maturation of the process into use in high integrity applications.[1–3]

Although research interest in this area has been prodigious recently, one method which not been widely explored is in monitoring the layer thickness during the build. This is expected to be an important parameter as it affects the fundamental melting of the powder in the process. Mahmoodkhani et al[4] used a novel print geometry to measure the layer thickness of a single layer ex situ and found substantial variation in the measured layer thickness relative to the nominal value. However, this does not offer any temporal resolution through the build and is disruptive, making it unsuitable as a methodology for monitoring layer thickness throughout a build.

In this paper, position measurements of the top surface layer recorded throughout a build are presented for the first time. A cylindrical component with varying inter layer dwell time has been manufactured, and the impact of this on

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the measured layer thickness is quantified using the monitoring setup developed. The utility of a laser position measurement system as an in-process monitoring tool in LPBF is also discussed.

2 | MATERIALS AND METHODS

A Keyence LK-G80 laser displacement sensor was integrated into the build chamber of a Renishaw AM250 machine in such a manner that it could record continuously throughout a build. The sensor was mounted parallel to the building substrate at a vertical distance of 95 mm from the build top surface. The spot size of the measurement laser beam on the part surface was approximately 70 μm. A CAD model depicting the setup can be seen in Figure 1.

A cylindrical component of diameter 8 mm by height 60 mm was built beneath the sensor such that the displacement of the top surface of the part relative to the 95 mm reference distance was logged throughout the build with very high temporal resolution. The interlayer dwell time experienced by the cylinder was also varied through the build. During the first 20 mm or 400 layers, of the build there was a 20-second dwell time between each layer scan. Between 20 and 40 mm, the dwell time was reduced to 11 seconds before increasing back up to 20 seconds for the top 20 mm of the part. This was achieved using the same procedure as in Williams et al,[5] and more comprehensive information on the influence of interlayer dwell time can be found there. A nominal layer thickness of 50 μm was used in the build. A photograph of the experimental build is shown in Figure 2, and some naming conventions are also annotated.

3 | RESULTS AND DISCUSSION

A plot of the displacement of the part top surface across three layers during the build is shown in Figure 3.

The signatures associated with several different process events can be seen in the plot, allowing the layer time to be measured, verifying its expected value of 20 seconds. As a characteristic signature can be identified for all the key events in a layer, the system will be able to detect variation in each of these signatures. This demonstrates the potential utility of implementing such a setup as an in situ process monitoring tool in LPBF. Significant variability can be also be seen

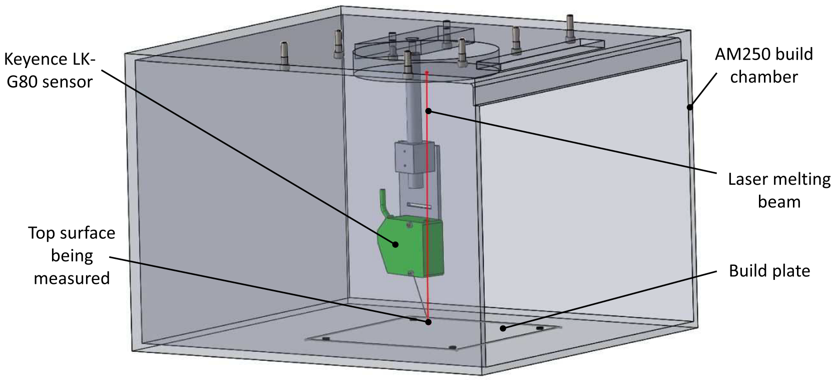


FIGURE 1 A CAD model of the AM250 build chamber (rendered in transparent), showing the mounted Keyence laser displacement sensor (in green) inside the chamber

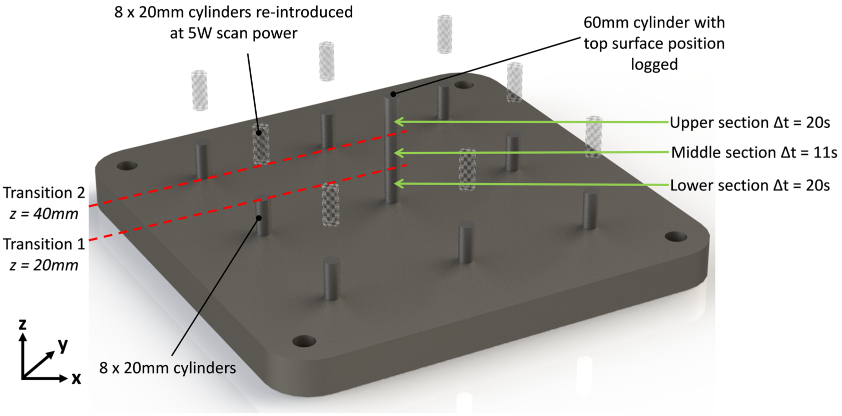


FIGURE 2 A photograph depicting the experimental build scenario and the tall cylinderical component, which was monitored by the Keyence sensor throughout the build. The variations in interlayer dwell time and the positions at which they occur are annotated

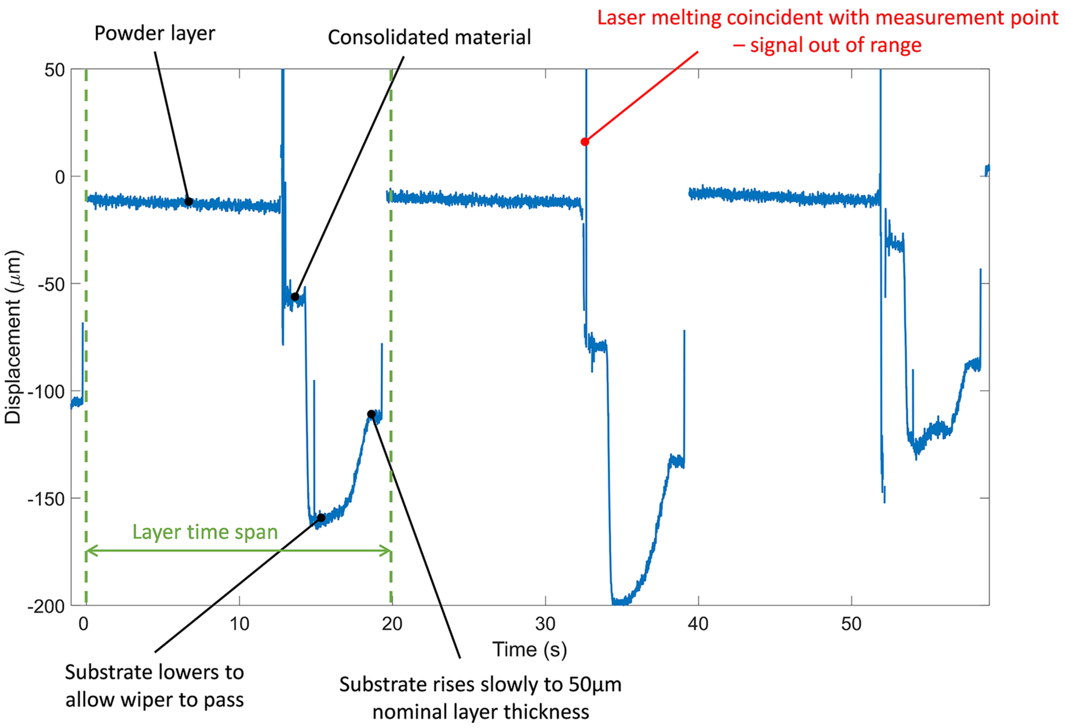
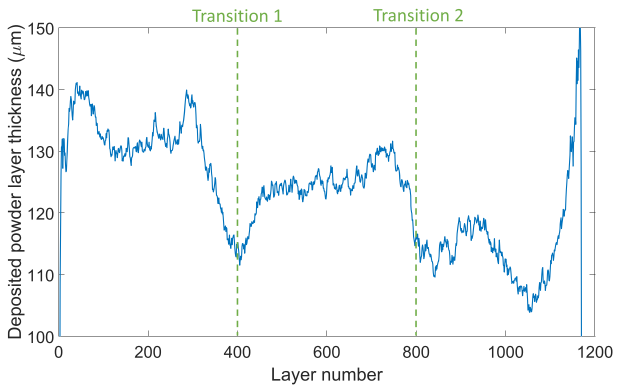


FIGURE 3 A plot of the position of the top surface layer across three layers during the first 400 layers of the build

in the surface height at corresponding points between layers, save for the absolute position of the powder layer which appears consistent. This value is not expected to change significantly else a collision with the recoating wiper could occur. Some of the variability may be caused by the measurement spot size of the sensor. Being 70 μm, this is only slightly larger the size of the powder particles, and as such, the spot may fall between particles or at different points of the surface roughness, creating the illusion of variablilty. The deposited layer of powder appears to be of the magnitude of 100 to 150 μm, which is significantly larger than the nominal 50 μm value of layer thickness expected in the process. Given the soft rubber material of the recoating blade in the Renishaw AM250, this is plausible. Variation in the amount deposited would also alter the amount of energy required to melt the layer and may impact the quality of the consolidation and density in the part, either through excess or insufficient energy input. In Williams et al and Yadollahi and Shamsaei,[5,6] correlation between the inter layer dwell time and lack of fusion porosity was found in both an identical experiment and when simplying processing fatigue samples. This could be an explanation of the mechanism by which it formed. A plot of the deposited powder layer thickness throughout the build can be seen in Figure 4.

Here, the effect of the variation in the inter layer cooling time can be seen, along with the general build-up of heat in the component throughout the build. Following the reduction in the inter layer dwell time at layer 400, the part is being scanned more frequently, increasing the rate of heat input. This causes it to increase in temperature and thermally expand, raising the height of the consolidated surface before the spreading of powder. As a result, a thinner layer

FIGURE 4 A plot of the thickness of the deposited powder layer throughout the build



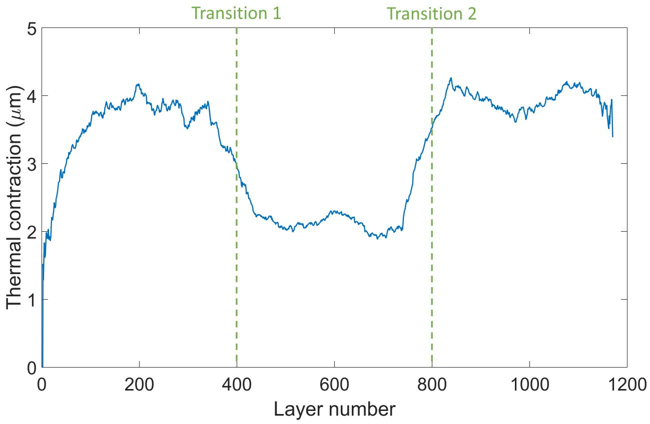


FIGURE 5 A plot of the measured thermal contraction occuring after melting but prior to powder deposition (or the inter layer dwelling time) throughout the build

of powder is spread during these layers relative to the first 400. At layer 800, the inter layer dwell time is increased again; however, the reverse effect is not seen. This can be attributed to the general building up of heat in the component throughout the build having a dominant effect. As such, the thickness of the deposited layer reduces further. The results of this study may be relevant to those attempting to implement high fidelity, powder-scale simulations as the results found here vastly different from the advertised layer thickness. There is currently a lack of empirical data providing input parameters for any such models, and a nominal and constant value is taken.[7] A plot of the thermal contraction measured in the desposited powder layer prior to scanning, throughout the build, is shown in Figure 5.

The variation in the inter layer dwell time can be again be noticed here. During the middle 400 layers, the time between the powder layer being deposited and it being melted is reduced by around 9 seconds. This means there is less time for the component to thermally contract during these layers. Hence, the amount of thermal contraction of the cylinder during this time reduced by 2 to 3 μm during the middle 400 layers.

It is the non-uniform thermal expansion and contraction which drives residual stresses to form in components during manufacture and they are of severe magnitude in LPBF due to the high thermal gradients involved. As such, variation in the thermal contraction thorughout the process is likely to effect the resultant residual stress field formed in the part. Detecting the ocurrence of such events provides the possibility of identifying defective zones in components or taking remedial action in the form of a feedback loop. Monitoring the position of the top surface layer during the process has demonstrated potential for use as a tool in carrying this out.

4 | CONCLUSIONS

In this work, a Keyence laser position sensor has been integrated in the build chamber of an LPBF machine with the capability of monitoring the position of the top surface layer throughout a build. A cylindrical component was manufactured and had its top surface position logged using the setup. It was subject to a variation in interlayer dwell time throughout the build. The following can be concluded from the study:

- A process signature could be detected from each of the key process events which take place in a layer. This demonstrates the potential for utilising a laser displacement sensor in this manner as an in situ process monitoring tool
- The measured thickness of the deposited powder layer varied significantly throughout the build and was consistent on the order 100 to 150 μm, far greater than the nominal 50-μm value which was set
- A variation in both the thermal contraction and deposited powder layer thickness was detected as a result of the change in the interlayer dwell time

5 | ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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