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Defect Detection in Additively Manufactured Components: Laser Ultrasound and Laser Thermography Comparison

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Abstract

Despite continuous technological advances in additive manufacturing, the lack of non-destructive inspection techniques during the manufacturing process is a limit for the industrial breakthroughs. Additive manufacturing is mainly used in industrial sectors where the zero defect target is crucial. The inclusion of the integrity assessment into the additive manufacturing process would allow corrective actions to be performed before the component is completed. To this end, the development of in-process monitoring and processing techniques is of great interest.
This work proposes and compares two remote non-destructive inspection techniques: laser ultrasound and laser thermography. The two techniques are evaluated on Inconel samples with laser drilling holes to establish their sensitivity. Experimental results show that those discontinuities are efficiently detected with both techniques. The remote inspection by optical methods would allow the integration of the evaluation system into the additive manufacturing equipment, thus allowing continuous monitoring throughout the entire production process. Potential benefits and limitations of the two techniques are discussed.

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Keywords: Additive Manufacturing; IR Thermography; Laser Ultrasound; Defect Sensitivity

1. Introduction

In the last decade, additive manufacturing (AM) process has gained an increasing attention for the production of 3D geometries or repair of high-value components. Very fine and complex structures can be built up layer upon

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layer. Better accuracy for complex structures can be achieved with AM if compared to traditional manufacturing methods. Moreover, mechanical properties of AM components approach and in some cases exceed the properties found in conventionally processed structures, as shown in Lewis et al. (2000). Interlayer and intralayer defects are often observed in AM components as shown by Ahsan et al. (2011) using scanning electron microscopy and microcomputed tomography.

Additive manufacturing seems to be a potentially growing market in every manufacturing sector such as automotive, aerospace, military and medical. New and improved technologies, large application area and ease of development of custom products are the major drivers that can push the AM market. However, a few factors restraining the growth of this market are material characterization during development, process control and integrity control. In-line inspection has important implications for those sectors where validation of AM components has until now been difficult to achieve. Conventional non-destructive techniques (NDT) cannot cope with the complicated geometries typically produced by additive manufacturing. Currently, the quality of AM components is assessed by destructive testing or by X-ray computed tomography (CT) (Thompson et al. (2016)) after the part is finished, which means that parts may be rejected after all the manufacturing is completed.

For critical requirements of quality, even in parts with complex forms, the desired solution is a non-destructive technique that allows in-line inspection and detection of flaws as the layer is deposited, so that the process can be controlled and corrected. Moreover, the non-destructive technique should detect micrometric flaws that are typical in AM products.

Some NDTs for AM parts have been investigated. The use of an ultrasonic squirter probe with a standard industrial robot to inspect a 3D metal deposition structure is demonstrated by Nilsson et al. (2012). Laser-generated surface waves have been used by Nemeth et al. (2005) to interrogate laser powder deposition parts, in both stainless steel and titanium, with pores that are simulated using blind holes. Clark et al. (2011) have shown the potential of an all-optical scanning acoustic microscope instrument for online inspection of AM products.

The use of ultrasonic laser transmitter and receiver and the interaction of the incident wave with sub-surface and surface defects have been widely investigated for many different applications (Kromine et al. (2000), Klein et al. (2004), Edwards et al. (2011), Pelivanov et al. (2014), Cerniglia et al. (2015)).

A promising NDT active thermographic technique, recently used for the surface crack sizing with micrometric aperture, is the flying laser spot technique. Li et al. (2011) developed a thermographic imaging technique using the second spatial derivative of acquired flying laser spot and line thermograms, in order to characterise micrometers cracks in metal samples. Burrows et al. (2007) used the laser spot imaging thermography and, simultaneously, laser-based ultrasonic measurements to find surface breaking cracks. Using the same flying laser spot set-up with a novel post-processing approach, Montinaro et al. (2017) have successfully implemented the technique for the detection and characterisations of disbond and delamination in fibre metal laminates. The thermal footprint left by the moving heat source is monitored, looking for thermal anomalies in a region of interest via a statistical approach.

The aim of this work is to prove and compare the laser ultrasound and laser thermography as techniques that might be deployed for the inspection of AM layers to detect near-surface and surface defects. The two NDT techniques have been tested and evaluated on Inconel samples with micrometric laser drilling holes. Potential benefits and limitations of the two inspection techniques are discussed.

2. Experimental procedure

2.1. Samples

Reference samples in Inconel 600 have been used. Flaws were created in standard geometries to establish the sensitivity to defect detection. Laser drilling was used to create holes in the samples, with different diameters (ϕ) and depths (d) below the surface. The two geometries of samples are shown in Fig. 1. Sample 1 is a plate with holes below faces A and B at different distances from the edge (Fig. 1(a)); sample 2 has a raised portion, representing the first layer above the substrate, where holes were drilled (Fig. 1(b)). After laser drilling, dimensions and depths of the holes were measured. Flaw sizes and depths are reported in Table 1.