Location of Cracks Occurring in an Additive Manufacturing Process by Acoustic Emission

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Abstract. Additive manufacturing is a modern technology that remains on the fringes of conventional manufacturing. Reasons for lack of industrial adoption include lack of repeatability, variation of mechanical properties and a relatively high chance of failure. This makes the development of in-process condition monitoring techniques a high priority. In this paper the use of acoustic emission for identifying when and where defects are occurring is examined. To do this sensors were placed on waveguides which were secured to the four corners of the heat assembly, onto which the build plate is attached. The Hsu-Neilsen method was then used across a grid drawn onto the plate in order to attempt to locate the signals. Test signals were located to within 13mm of the actual location despite the complex geometry of the plate assembly. Signals were then detected from a build and located on the plate through use of the traditional TOA method and the Delta T Method.

Literature Review Selective Laser Sintering (SLS) is a method of additive manufacturing, popularly known as 3D printing, in which powder is laid down in layers then fused by use of a high-power laser. SLS is part of a family of processes known as powder bed fusion (PBF) that also includes directed energy deposition (DED), electron beam melting (EBM) and selective laser melting (SLM). SLS was later adapted for use with metallic powders, with metals with good weldability and resistance to cracking being favoured. This has also seen SLS transition from being used mainly for rapid prototyping to full complete parts.

In SLS a layer of powder is rolled across a build plate at a thickness of around 20-100µm [1] which is then sintered in a pre-programmed pattern before the bed is moved down to allow another layer to be sintered. The pattern that is sintered is based on a CAD model that has been sliced by a specialist software that allows the laser to scan that specified slice. The powder immediately around the laser spot forms a highly turbulent melt-pool which will solidify as the laser moves away, though it will be partially re-melted when the laser welds the layer above. This heating and cooling of powder leads to thermal stresses building up within the part. The increased weight of part being exerted on lower layers as the part builds up can also lead to residual stresses being built up in the part.

This tendency to build up stresses can lead to variation in mechanical properties and a lack of repeatability [2]..Porosity can also be a major issue for AM parts unless post processing techniques are used. Despite this, AM has many advantages over traditional manufacturing. AM allows a lot more freedom in manufacturable geometry and can be quicker than many fabrication methods due to being a single process. In order to confirm the strength of an AM part currently there are a number of post-processing techniques that are commonly used in to check for porosity and defects. The industrial standard for investigating porosity and internal defects is X-ray tomography [3]. However, this is an expensive and time consuming process and not practical for large numbers of parts.

In-processing monitoring normally involves monitoring process parameters or process signatures. Process parameters are aspects of the process that can easily by adjusted through the machine software such as laser energy, laser scanning velocity, hatch distance, powder layer thickness and scanning strategy. Process signatures arise during from the part during manufacture and typically include melt pool properties such as depth shape and temperature, or other characteristics linked to the heating, melting and solidifying of the powder.

Many studies have looked at how process parameters affect part quality, such as scanning speed [4,5], beam energy [6] and layer thickness [7]. Monitoring methods used in other studies have included melt-pool shape monitoring [8], melt-pool temperature monitoring [6], surface acoustic waves (SAW) [9], optical coherence tomography [10] and X-ray imaging [3].

A potential avenue of process monitoring that has yet to be assessed in this field is acoustic emissions (AE). Acoustic Emissions are the phenomenon where elastic energy is released from discontinuities in a material due to mechanical loading. This can occur due to plastic deformation, crack tip advancement or frictional behaviour [11].

The stress wave propagates in all directions from the source, reflecting off the boundaries of the part. Surface displacements generated by the wave are detected by piezoelectric sensors which convert the wave to an electrical signal. This signal can then be used to identify the type of defect and its location.

There are several challenges associated with the use of AE. Background noise can be a major issue, especially in a process monitoring situation. It is important to gain a full understanding of the acoustic signature of different types of defects from different densities of material. For example emissions from the bulk material may be more relevant to the quality of the build than emissions originating from the lower porosity support material.

Experimental Work The 'Delta T Mapping' technique [12] was used to map the build plate and heater plate. Delta T first involves creating a grid on the desired surface then obtaining time of arrival data from each point on that grid using an artificial source. The Hsu-Neilsen method was used to produce artificial AE signals from which a specialised Matlab code creates 6 maps for 4 sensors; one for each pair of sensors. These maps show the difference in time of arrival between sensors. After this a number of test locations are chosen to verify the accuracy of the maps.

In this project a 250x250mm build plate from a metal SLS machine was mapped using Delta T. This is the plate that the part is built on, which is affixed to the heater assembly, which in turn has piezoelectric sensors bonded in each of its 4 corners. A 200x200mm grid was drawn onto the build plate, with grid spacing of 20mm, all centred on the centre of the plate. This produced 11 points per line, and 11 lines, meaning a total of 121 points from which to create the Delta T Map. Multiple Hsu-Neilsen Source Tests were then carried out for each line on a point by point basis, with the waveforms recorded using AEWin.

Results and Discussion. Using the Delta T grid, signal source locations were identified with an average error of 13mm, and over 90% of signals identified. Most missed signals occurred in the corners of the plate. This could be due to the large time difference between reaching opposite sensors and the effect of reflections. To check the effect of the build plate on wave propagation this was repeated with the plate removed, and signals were better located on the edges especially.

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