Predicting Heterogeneity and Defects in Additive Manufacturing

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Additive manufacturing (AM) is an exciting up-and-coming near-net-shape technology that is in the process of being rapidly industrialised for aerospace manufacturing. AM is extremely attractive to the aerospace industry as it allows great design flexibility, reduces lead times, and most importantly greatly reduces the amount of machining required to produce components made out of expensive and difficult to machine materials like titanium alloys. For example, the buy-to-fly ratio for a typical titanium component machined from forged billet is 10 - 20:1 compared to 2 - 7:1 when manufactured by AM. A range of AM platforms are available from laser and electron beam powder bed, to blown powder and wire based systems, such as plasma or laser wire deposition. These systems vary in resolution (layer height) and the deposition rate and size of components that can be built. There is thus a trade-off between precision and component scale; i.e. laser powder bed is most suitable for complex high precision, but small (typically less than 0.5 m), components, whereas plasma wire deposition can be used to produce large less complex parts (over 10 m in length). Although a lot of work has been done to develop these technologies surprisingly little work has been devoted to understanding the materials issues they present, particularly in terms of their microstructure and property variability, which is a key issue for qualification.

In AM the material solidifies in a small moving melt pool, and material is built up with many overlapping raster tracks, leading to very high solidification and cooling rates and a complex cyclic thermal history. The microstructures produced are thus novel and their deformation behaviour and response to fatigue loading is still poorly understood at a fundamental level. Furthermore, the microstructures tend to show heterogeneities, such as banding, due to the variable temperature experienced during layer deposition and can be sensitive to the raster pattern, or the build strategy used and the part geometry. The small melt pool solidification conditions in AM also tend to promote very coarse directional primary grain structures, particularly in titanium alloys. In addition, defects such as porosity are often observed, particularly in powder-based systems.

LATEST2 is heavily involved in developing an improved understanding of AM materials and their mechanical performance. As a first step, we are developing automated tools to quantify and map the defect content, microstructure, texture and its heterogeneity within a component, to facilitate a better understanding of the relationship to the process variables e.g. what happens when there is a local change in section thickness? We are also developing the capability to understand how this affects the materials' mechanical behaviour at a fundamental level; for example, how defects, local texture and microstructural variation affect crack propagation under fatigue loading, and in the long term we hope to develop models to predict the microstructure in AM processes.

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Fig. 1 A geometrically optimised design for a hinge bracket produce by AM (Coutesy of EADS).

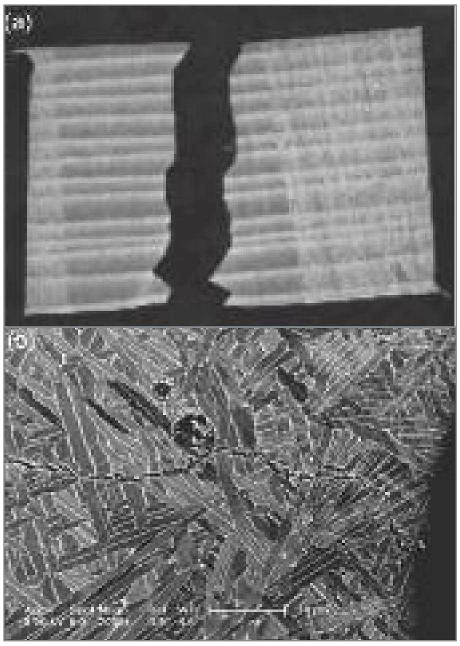

Fig. 2 (a) Effect of microstructural banding on macroscopic fatigue crack growth and (b) an example of a crack connecting a pore through the complex Widemanstätten – colony alpha transformation microstructure found in a titanium 64 Wire-Arc titanium deposit.

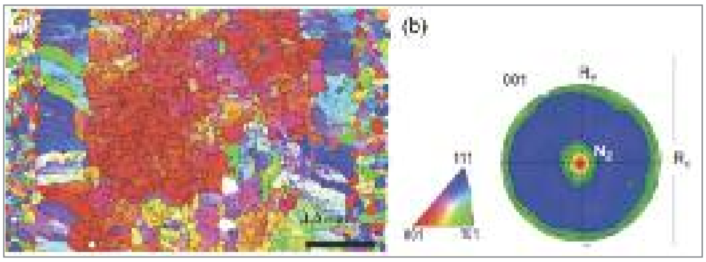

Fig. 3 IPF contrast EBSD map (a) of the reconstructed β grain structure seen in a cross section a Ti64 AM component, produced by through an electron beam powder bed procures, showing the different grain structure in the section outline contour pass compared to that generated by infill hatching. Note the strong <001>β fibre texture (red) in the bulk of the part – accompanying pole figure (b).

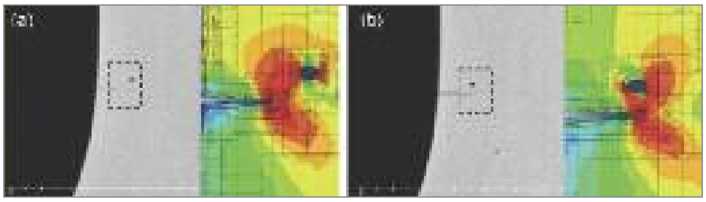

Fig. 4 3D X-ray tomography of a crack growing in a fatigue sample and an FE model constructed of the actual crack – directly from the tomography data – to see how crack growth is affected by pores present in an electron beam powder bed produced test sample.