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MICROSTRUCTURE AND RESIDUAL STRESS IN TI-6AL-4V PARTS MADE BY DIFFERENT ADDITIVE MANUFACTURING TECHNIQUES

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Introduction

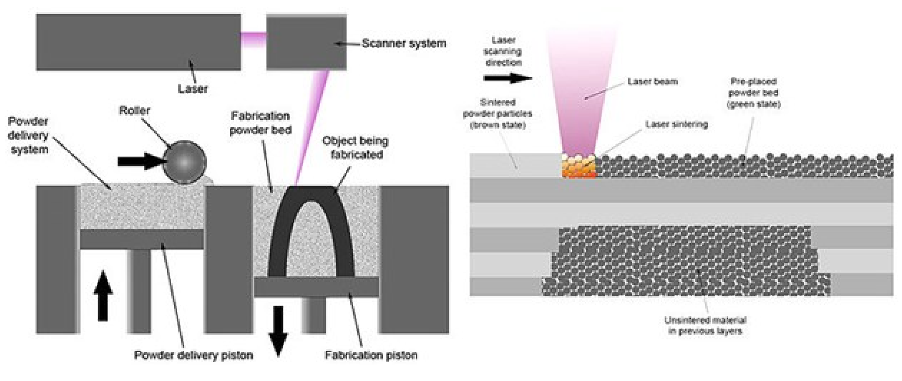
Additive manufacturing (AM) also known as solid free form fabrication or additive fabrication, additive layer manufacturing, direct digital manufacturing and 3D printing, is rapidly growing as an advanced manufacturing technology. At present, two major groups of AM techniques, namely powder bed fusion (PBF) and directed energy deposition (DPD), are available. The AM techniques are classified based on the heat source used for the manufacturing process whether it is provided by laser, or an electron beam. Disregarding the AM manufacturing method, the material's mechanical properties, residual stress level and surface quality are the major limitations preventing the uptake of the technology to produce components for demanding engineering applications. The objective of this study is to obtain more in-depth knowledge of microstructure and residual stress developments in Ti-6Al-4V cylindrical parts made by different AM techniques, and compare the results with parts made through traditional manufacturing practices (i.e. Ti-6Al-4V_ELI).

Experimental

Five different components of the same material made through different manufacturing routes, including traditional forging and AM methods: electron beam melting (EBM), direct metal laser sintering (DMLS), and laser metal deposition (LMD), were analysed. These include microstructure characterisation and residual stress measurements by x-ray diffraction (XRD) and a hole-drilling technique based on electronic speckle pattern interferometry (ESPI). The material produced by AM techniques was compared with the mill-annealed condition of conventionally produced material.

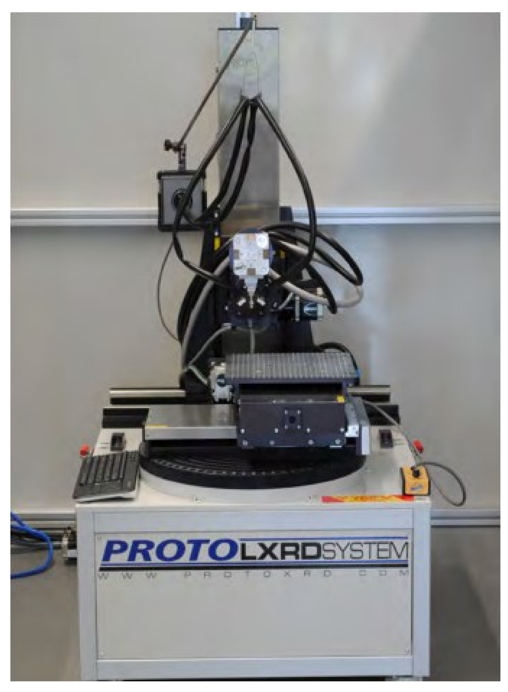
Electron beam melting

Selective laser sintering

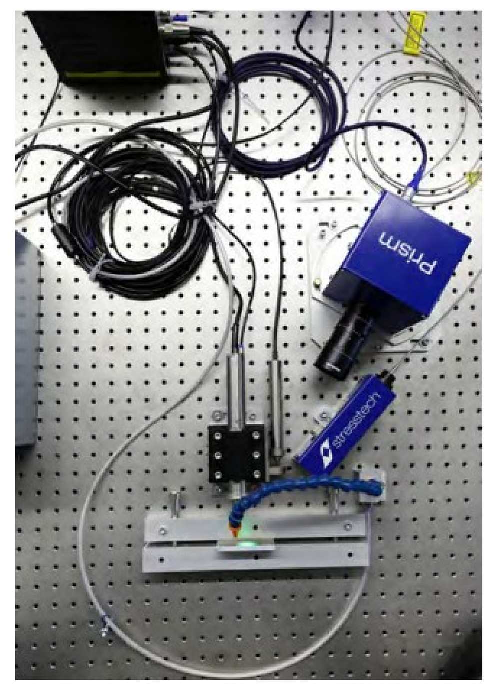


Laser metal deposition

PROTO LXRD

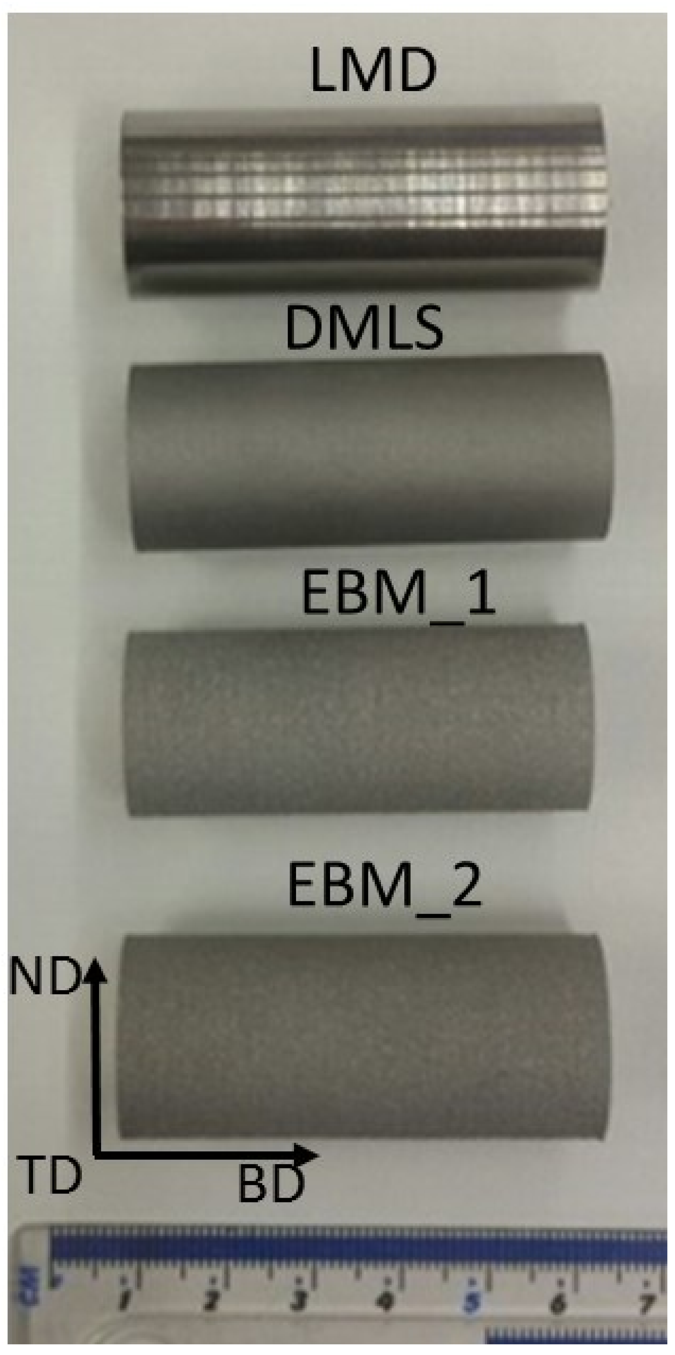


Electronic Speckle Pattern Interferometry (ESPI)



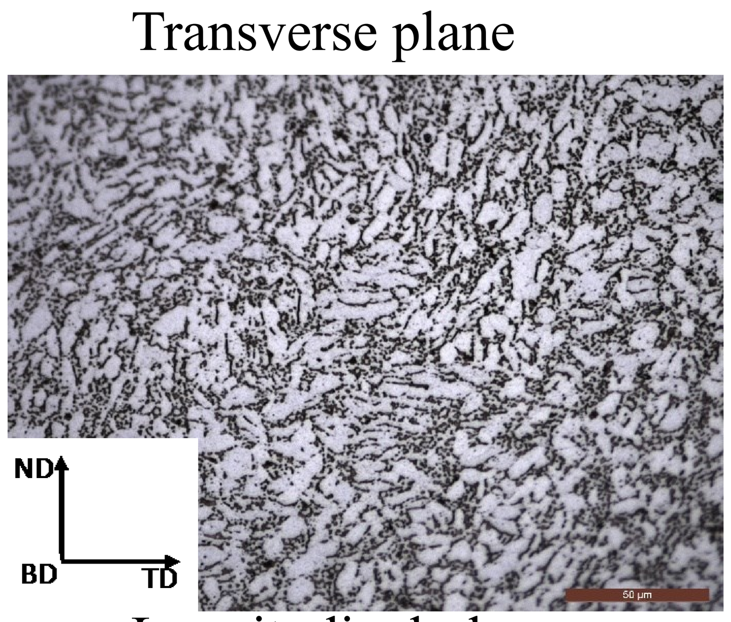
Results

As-received AM material

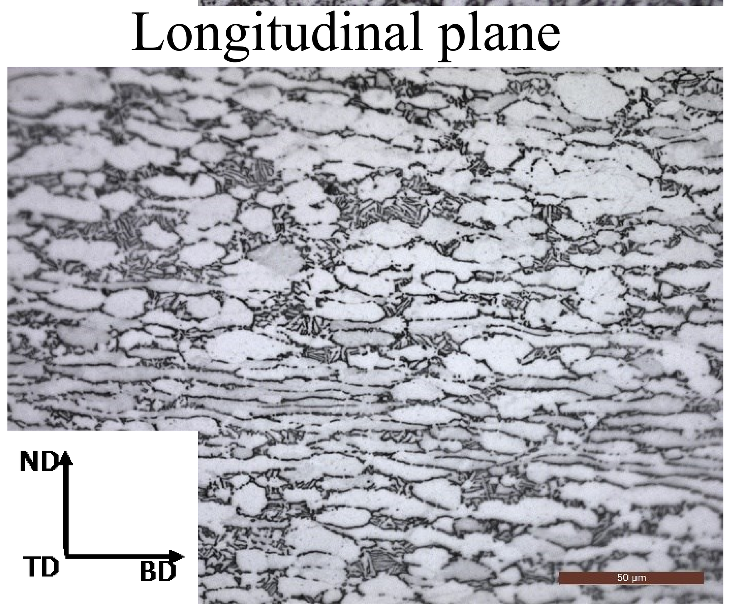


A significant difference is found between the surface properties of the as-received AM materials. The laser-based techniques provided better surface quality (i.e. lower roughness) as appose to the electron-beam technique.

Ti 64 ELI
Transverse plane

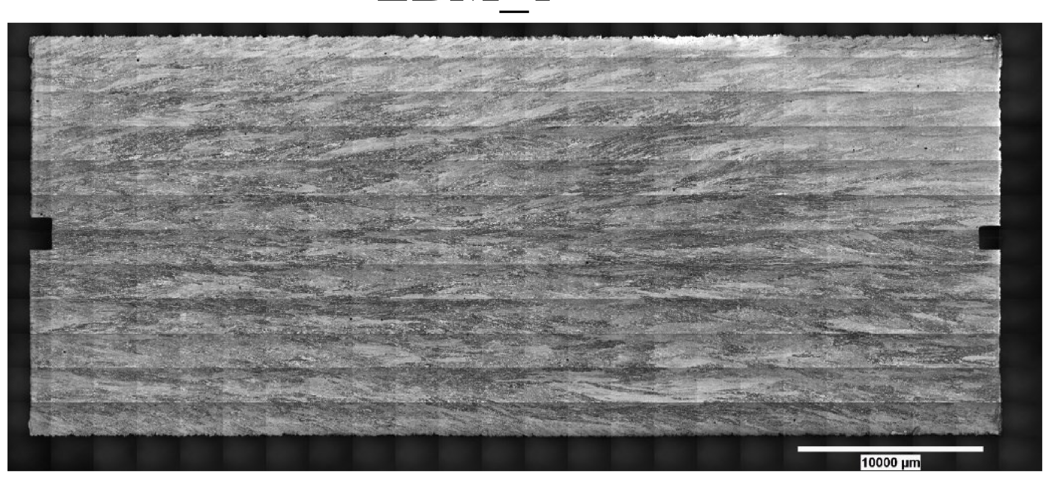


Longitudinal plane

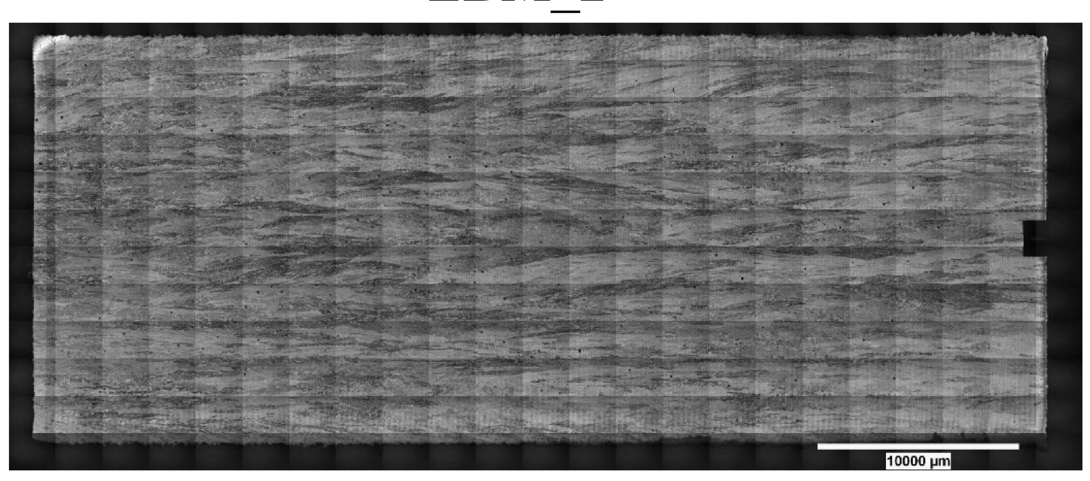


Material produced by EBM and LMD was found to be characterised by large initial β-grains elongated in the direction perpendicular to the additive layers. In contrast, almost equiaxed initial grains were found in DMLS material.

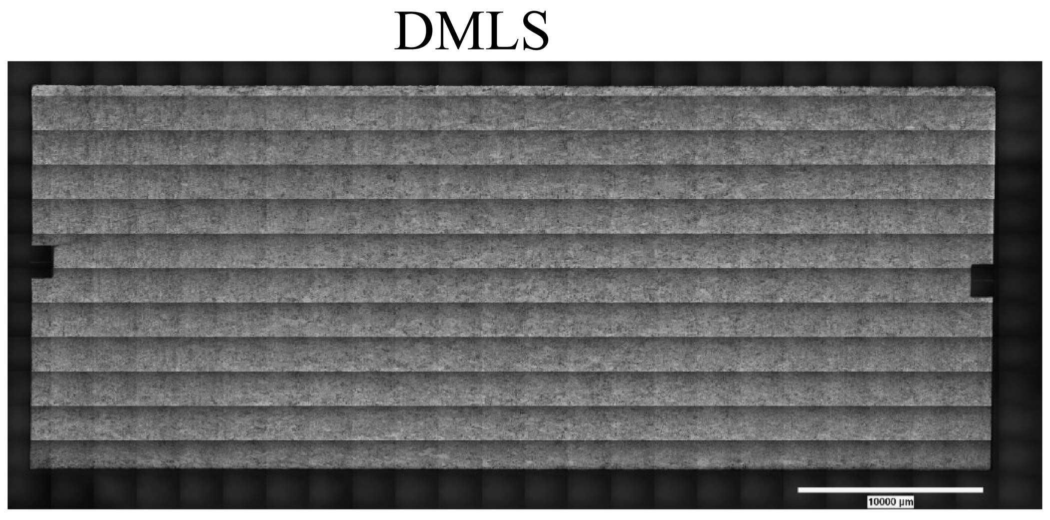
EBM_1



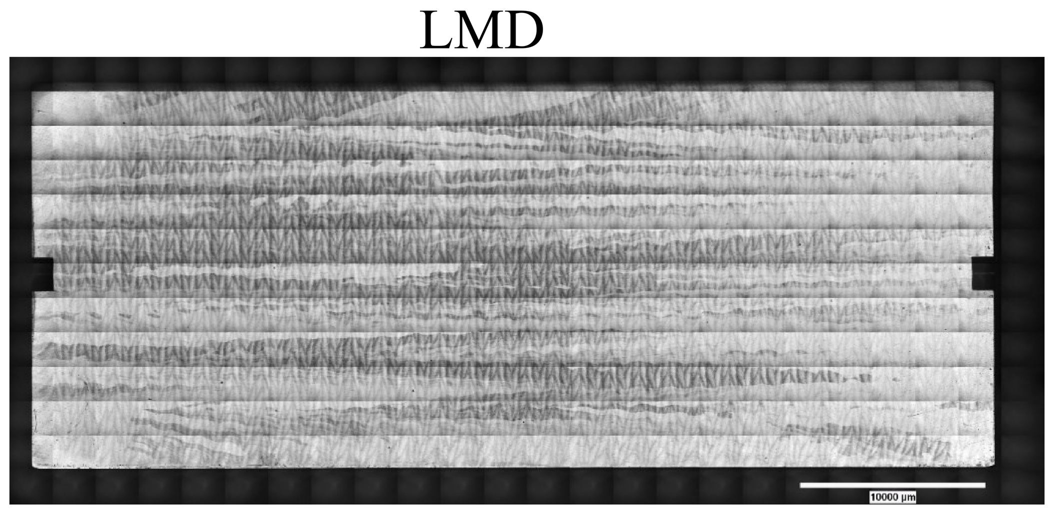
EBM_2



DMLS



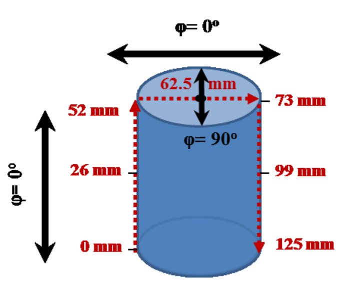
LMD

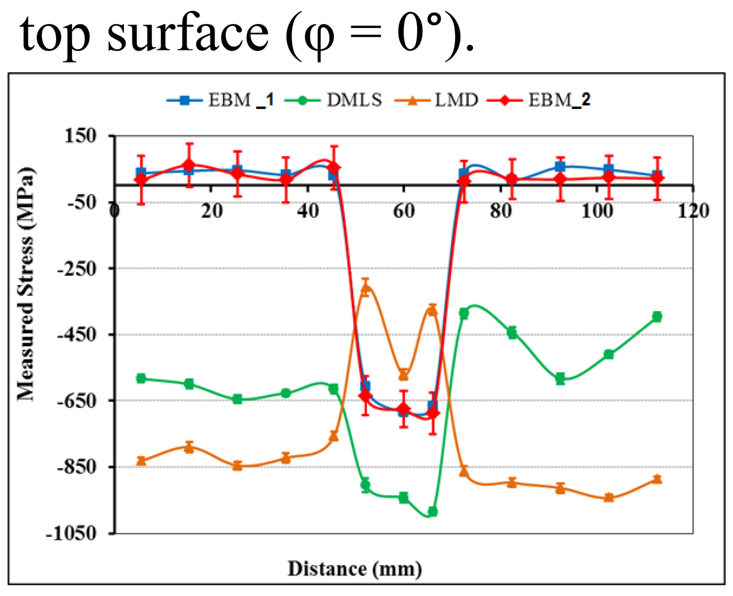


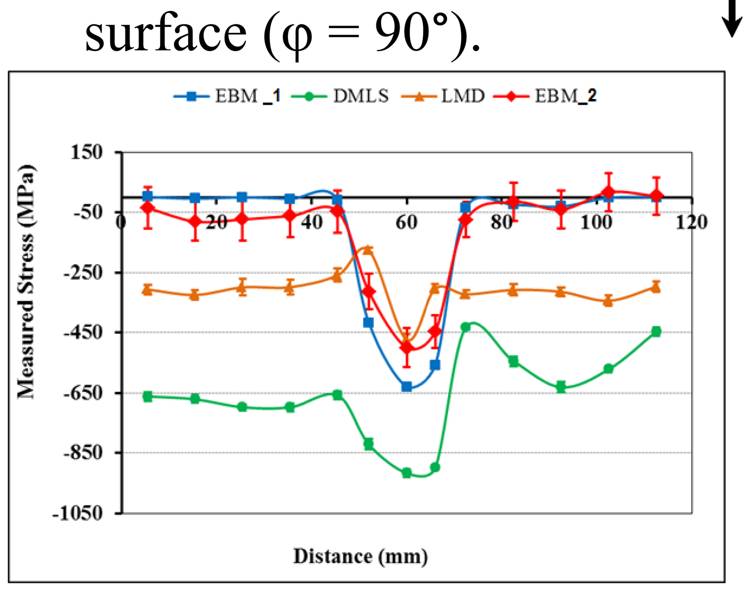
XRD

Axial stress on the side surfaces and radial residual stress on the top surface (φ = 0°).

Hoop stress on both the side surfaces and top surface (φ = 90°).





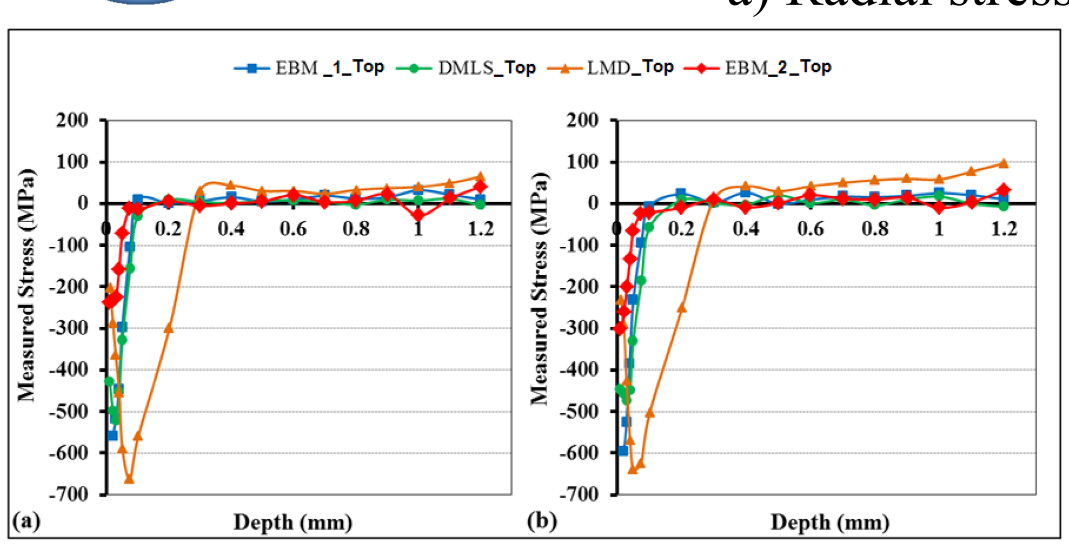


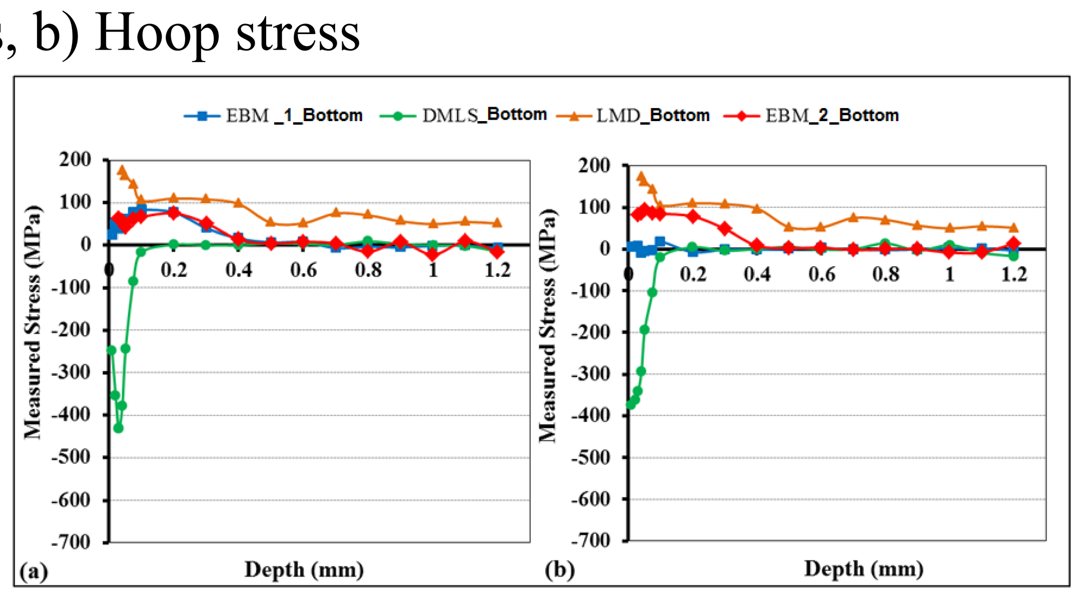
ESPI

top surfaces

bottom surfaces

a) Radial stress, b) Hoop stress





Conclusions

- The nucleation of the initial β-grains during AM processes was found to be orientation dependant and not random; the oriented nucleation was more evident in EBM materials, as well as DMLS material. Grain nucleation and growth tend to occur in the direction of cooling which is dominant in the sample's longitudinal direction (i.e. normal to the additive layer plane).
- The residual stress components measured by XRD on the finished surfaces of all AM samples, were found to be significantly compressive. ESPI results exhibited a significantly high level of compressive residual stress on the top surfaces, then gradually reduce to stress free conditions after 150 μm for all of the AM samples except LMD which reduced to stress free status after about 300 μm.

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