Determination of Residual Stress in Additively Manufactured Parts by Synchrotron X-ray and Neutron Diffraction

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Neutron diffraction (ND) and high energy synchrotron x-ray diffraction (SXRD) are both diffraction-based techniques which are capable of probing the internal residual stresses of a crystalline material. The laser powder bed fusion (LPBF) manufacturing technique uses scanning of a focused laser to selectively melt a thin layer of metal powder which then solidifies into a single layer, and over many layers this produces a full 3D component without the need for casting or machining [1,2]. This manufacturing technique results in residual stresses within the finished part as the part undergoes many localised high gradient thermal cycles [3] as the laser scans over the part. This generally results in a tensile surface stress in the part balanced by a compressive stress in the base plate [4].

The uptake in determining residual stress by diffraction for LPBF components has generally been with the aim to evaluate the difference in residual stress induced by some change in the manufacturing or processing parameters, to compare to results obtained by lab-based techniques such as the contour method or to validate computational models. In this work, by conducting a series of measurements at different instruments, the reliability and repeatability of diffraction techniques for the determination of residual stress in additively manufactured parts has been investigated confirming them as appropriate for the above use cases.

Determination of residual stress by diffraction in LPBF additively manufacture 316L stainless steel arches was accomplished with 4 strain scanners, through SXRD (P07 and P61A at DESY operated by Hereon [5] and ID15A [6] at ESRF) and ND (SALSA [7] at ILL). The arch shape was chosen as it contains an overhang which is a common geometry in additive manufacturing. Measurements were carried out along two lines, the first from the top surface to the centre of the apex of the arch and the second perpendicular to the first 1 mm deep into the part. These measurement paths and the arches are visualised in Fig 1. The in-plane stress profile along line 1 for all of the strain scanners is shown in Fig 2.

The general trend of stress is that of tensile at the surface and compressive close to the apex of the arch. This trend is seen by all strain scanners and is a stress profile consistent with solidification-induced residual stress build up imparted through the many layers of the LPBF process. The strain scanners generally show good agreement throughout the measurement path. There are however local variations and, in some cases, systematic offsets in some locations. The possible causes of these discrepancies will be discussed, as they are considerations which must be made when determining bulk residual stress by diffraction. These include gage volume sizes and shapes, positional uncertainty, attenuation, fitting of diffraction peaks, as well as the choice and measurement of the stress-free reference.

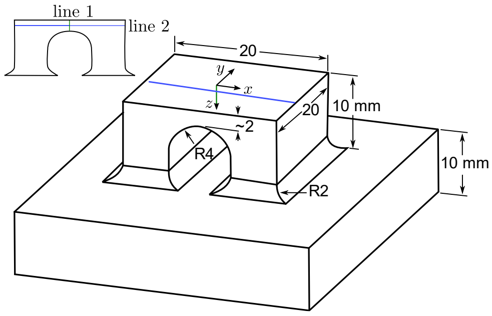

Figure 1 AM Arch dimensions and co-ordinate system. Cut out showing the two measurement paths, vertical line 1 (green) and horizontal line 2 (blue).

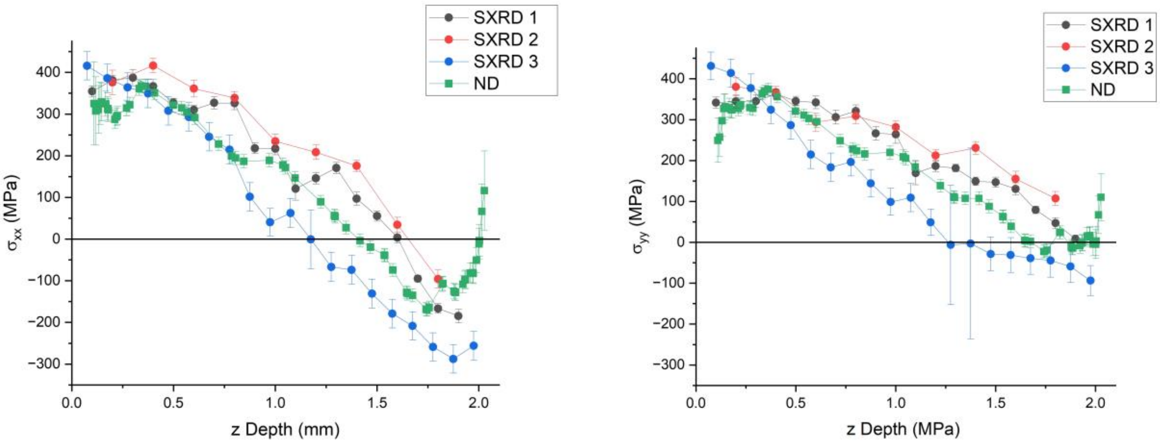

Figure 2. Residual stress in the x direction, σ_{xx}, and y direction, σ_{yy}, along line 1 determined by SXRD (black, red, blue) and ND (green).

References

[1] S. Chowdhury, et al. J. Materials Research and Technology, Vol. 20 (2022) p 2109-2172.

[2] S.R. Narasimharaju, et al. J. Manufacturing Processes, Vol 75 (2022) p 375-414.

[3] P.A. Hooper, Additive Manufacturing, Vol 22 (2018) p 548-559.

[4] C. Li, et al. Procedia CIRP, Vol 71 (2018) p 348-353.

[5] N. Schell et al. Materials Science Forum, Vol 772 (2014) p 57-61.

[6] G.B.M Vaughan, et al., J. Synchrotron Radiation, 2020. 27(2): p. 515-528.

[7] T Pirling, G. Bruno, and P.J. Withers, Materials Science and Engineering: A, Vol 437 (2006) p 139-144.