Non-destructive characterization of internal surfaces in LPBF Inconel 718 channels

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LPBF manufacturing of coolant channels

Laser Powder Bed Fusion (LPBF) is used to manufacture modern turbine engines with integrated thin cooling channels of different orientations. The surface quality of the internal channels which is determined by the LPBF process parameters and depends on the build direction [1]. In order to minimize defects arising from downskin effects and adherend unmelted powder particles (Fig. 1), subsequent chemical surface treatments are applied. The presented non-destructive computed tomography (CT) analysis method provides a comprehensive quantitative characterization of internal surfaces before and after treatment and optimizes etching methods.

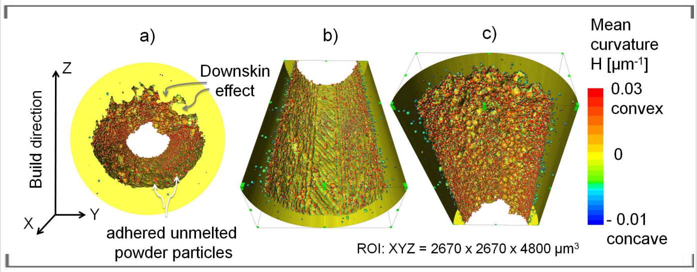

Fig. 1: LPBF channel produced horizontally (0°) (a), its lower (b) and upper (c) parts.

Analysis method

- Cylindrical specimen, manufactured with LPBF on a Concept-Laser M2 machine from Inconel 718.
- LPBF bulk and contour parameters previously optimized on specimen with external surfaces of different orientations [1].
- Build orientations of specimen: 0°, 30°, 60° and 90 (Fig. 2a).
- Subsequently, two sets of as-built specimen were etched chemically at two external companies with special procedures.
- CT: Phoenix© Nanotom tomograph, resolution of 2.2 µm/pixel (Fig. 2b). Averaged 2D roundness Φ, equivalent diameter D_{eq}, and a radial roughness distribution S_z were calculated from sections perpendicular to the channel axis (Fig. 2c) [2]. The mean curvature distributions H were also evaluated using AVIZO©.

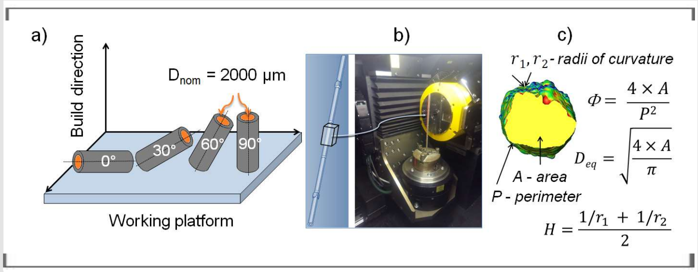

Fig. 2: Build direction of the specimens with channels (a), CT examination (b) and an example of a 2D cross section perpendicular to the channel axis (c).

Results

- Non-destructive Computer Tomographic (CT) allows highly resolved analysis of the inner channel surfaces before (as-built) and after surface treatment (examples in Fig. 3).
- For cooling channels used in modern turbine engines, it is important to optimize the average roughness as well as its deviations (distribution), since the inherent roughness can result in reduced flow rates due to high friction, possible turbulence, pressure loss and even cause particles detachment, which can damage other equipment.
- As-built channel quality:
  - is affected strongly by the build direction.
  - horizontal direction (0°, Fig. 3a, top): adherend powder particles and melt beads reduced effective diameter to D_{eq} = 1741 µm. Flattened profile. Φ ≈ 0.34.
  - vertical direction (90°, Fig. 3d, top): smoother, more rounded profile. Φ ≈ 0.91. D_{eq} = 1976 µm equals target value.
- After post-treatments:
  - significant improvements of internal roughness, particularly for specimen built at low inclinations.
  - 0°- and 30°-built channels (Fig. 3a and b, bottom): Φ increased to 0.78 - 0.93. The equivalent diameter D_{eq} also approaches the nominal diameter of 2000 µm.
  - comparative analysis of the two etching methods (Fig. 4): Radial distributions of in S_z values still vary significantly, but Φ and D_{eq} are similar.
  - surface treatment method 2 (Fig. 4c) leads to deep depressions quantified by a high ΔS_z up to 55 µm compared to 15 µm for method 1 (Fig. 4b).
- CT characterization of the channels in combination with this detailed analysis method allows significant improvements in internal surface quality, e.g., by means of systematically guiding the optimization of the LPBF parameters, the manufacturing strategies and the post-processing routes.

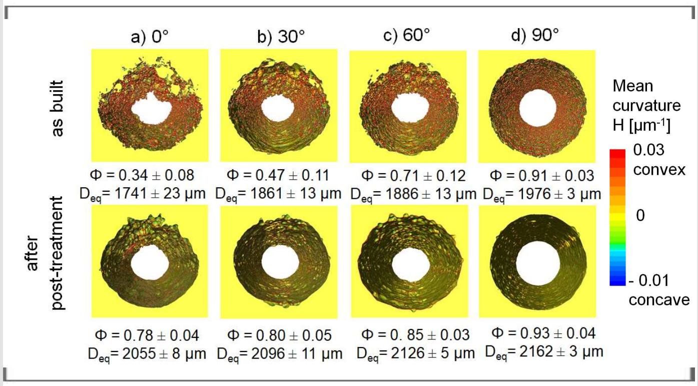

Fig. 3: Channel profiles before (as-built) and after post-treatment as a function of the build direction: for 0° (a), 30° (b), 60° (c) and 90° (d).

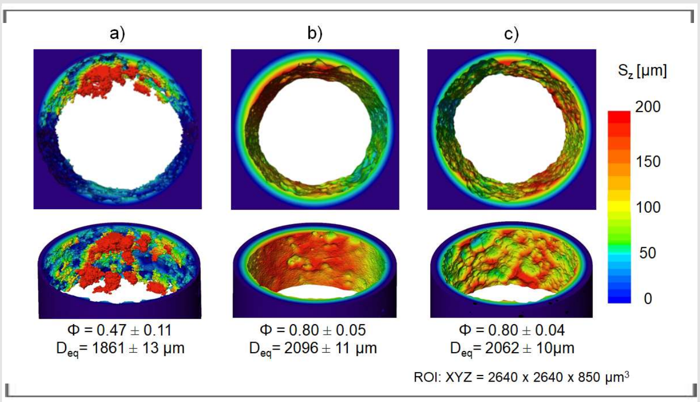

Fig. 4: 3D radial roughness S_z as a distance from the nominal channel surface (specimen built with 30° inclination): before (a) and after treatment by two comparative surface etching methods: (b) and (c).

References:

[1] G. Kasperovich, R. Becker, K. Artzt, P. Barriobero-Vila, G. Requena, J. Haubrich, Mat. & Design, 207 (2021) 109858.

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