Laser Powder Bed Fusion thermal monitoring using optical fiber sensors: in situ measurements and modelling

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Fusion-based metallic additive manufacturing (AM) features complex material and heat transfer phenomena. These processes dynamics can be monitored using different techniques in order to assess the manufacturing quality or detect defects. Fiber Bragg Gratings written using femtosecond laser pulses (fs-FBGs) inside optical fibers allow temperature multipoint sensing by monitoring the reflected wavelength λ_B of each wavelength-multiplexed sensor [1].

We have demonstrated in previous work [2] that the Laser Powder Bed Fusion (L-PBF) AM process can be thermally monitored close to the melt pool by using fs-FBGs. In this experiment, a 5 × 5 × 50 mm^3 316L stainless steel part was instrumented by an array of 3 fs-FBGs written in a polyimide-coated optical fiber, packaged in a 316L capillary (Figure 1a). An additional thickness of 2 mm (~30 µm layer thickness) was printed on top of the existing structure. Continuous temperature monitoring was performed by interrogating the three FBGs at 5 kHz (si255 sensing instrument, Luna Innovations). In order to assess in more details the performance of fs-FBGs in monitoring such transient thermal processes, we developed a simplified model and compared the results to the experimental measurements.

The model was implemented in Cast3M [3] taking into account the main heat fluxes at stake. The heat input generated by the laser beam scanning was modelled by a moving flux line perpendicular to the part's longitudinal axis. Different heat transfer coefficients were chosen to take into account: (a) the conduction to the substrate plate; (b) the conduction from the lateral sides to the surrounding powder; and (c) the forced convection from the inert gas flow. Material phase transitions were not modelled, and thermo-physical properties depending on temperature were extracted from Mills [4]. In Figure 1b, we compare the calculated temperature at the positions of the FBGs to the experimental measurements for one printed layer, corresponding to a deposited thickness of about 450 µm over the sensors.

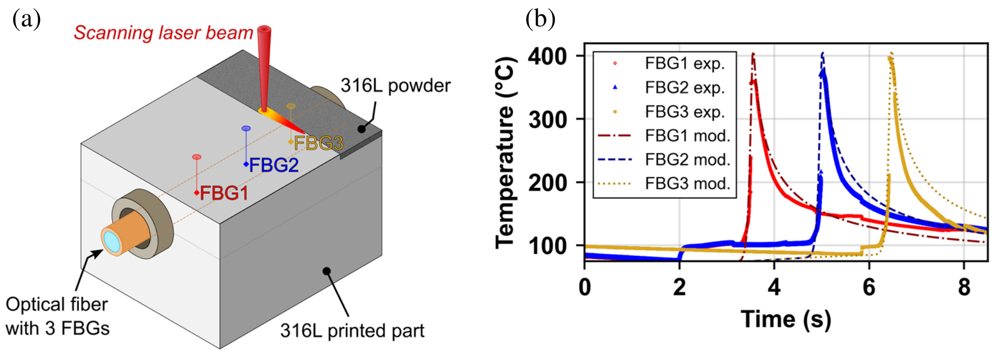

Fig. 1 (a) Schematic of L-PBF monitoring using an array of three FBGs (not to scale); (b) Comparison between experimental and simulated temperature values for each FBG sensor during the manufacturing of one layer.

Satisfying temporal adequacy is obtained regarding the successive heating of the three sensors. The error in peak temperature value is less than 10%. Heat transfer coefficients values refining is necessary in order to more accurately model the cooling, but the approximated values lead to maximal temperature errors of 20% during this step. This approach may allow to unravel the respective contribution of the multiple heat transfer phenomena at stake in the L-PBF process and their effect on the temperature field deep in the printed material.

References

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