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Synchrotron X-ray nano-tomography of Almazium: healing mechanisms of a new high-strength healable aluminium alloy produced by LPBF

Q. X-ray and neutron methods at large-scale facilities for materials and their processes: microscopy/imaging, diffraction, spectroscopy and spectromicroscopy

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Abstract

Aluminium alloys produced by additive manufacturing are largely used in aerospace and aeronautical fields where damage may occur due to overloads experienced in service. A promising approach to avoid the replacement of damaged parts by new ones is to use a material able to heal its damage sites.

The aim of this research is to design a new high-strength healable Al alloy manufactured by Laser Powder Bed Fusion (LPBF). The high cooling rate inherent to LPBF results in a refined microstructure consisting of α -Al cells enclosed by a Mg-rich low melting point eutectic network acting as healing agent, similarly to biological vascular systems. After damage, a healing heat treatment (HHT) induces the melting of this healing agent eutectic phase, enabling it to flow inside the defects to seal and weld them through solidification. Alternatively, a Healing Heat and Pressure Treatment (HHPT) can be applied, in which the isostatic pressure closes the cavities while the temperature welds them similarly to HHT. To enhance the strength of the alloy while maintaining its healing capabilities, Zr is dispersed into this Al-Mg alloy and forms hardening precipitates.

In this work, the healing potential by HHT and HHPT of this new Al-Mg-Zr alloy called Almazium has been characterised in 3D using synchrotron X-ray nano-tomography at beamline ID16B ESRF. This technique enabled high-resolution imaging (35 nm voxel size) of the damaged regions before and after healing. Following a HHT at 540 °C for 30 minutes, 42 % of the voids were completely healed, and the volume of voids with an equivalent diameter of 2 µm or less was reduced by at least 50 %. After applying a HHPT, no voids were detected, demonstrating complete healing. The damage healing ability of Almazium has been also assessed thanks to in-situ damage-healing cycles during synchrotron X-ray nano-tomography experiment. It allowed the observation of the damage mechanism, the local healing, and if the healed damage sites are source of new damage initiation during subsequent overloading.

The static mechanical properties of Almazium have been characterised both in the as-built state and after various HHT with different temperatures and durations. Under optimal manufacturing conditions, addition of Zr significantly enhanced the yield strength, increasing it from 150 MPa to an average of 408 MPa in as-built samples. The influence of LPBF parameters on the mechanical properties of Almazium has been characterised and explained through chemical composition analysis and advanced microscopy techniques, including optical and electron microscopy. Additionally, the temperature and duration of the HHT have been optimised to minimise excessive coarsening of hardening Zr precipitates, detrimental for mechanical properties.