IMPACT OF MICRO AND MESOSTRUCTURE ON THE FAILURE RESISTANCE OF LASER POWDER BED FUSION-PROCESSED MATERIALS

Bernd Gludovatz[1]*, Moses J. Paul[1], Jamie J. Kruzic[1], and Upadrasta Ramamurty[2]

[1]University of New South Wales (UNSW Sydney), Sydney, NSW, Australia
[2]Nanyang Technological University, Singapore, Singapore
** Presenting Author email: b.gludovatz@unsw.edu.au*

Abstract

Engineering materials processed using additive manufacturing (AM) techniques such as laser powder bed fusion (LPBF) often exhibit unique microstructures and defects that must be controlled to obtain peak performance in mechanical properties and as such a level of damage-tolerance that cannot be achieved in cast alloys. However, our understanding of how processing conditions control micro- and mesostructure and, in turn, mechanical performance, particularly regarding failure resistance, is weak. Furthermore, heat treatments that have been designed to achieve peak performance in cast alloys are often not optimized for alloys that have been processed using AM techniques. Here, we report our work on the effect of processing parameters such as layer thickness, hatch spacing, and scan strategy on crack resistance curve (*R*-curve) behavior in different orientations of LPBF-processed AlSi10Mg and correlate mechanical performance with meso- and microstructural features such as melt pool arrangement, cell morphology, grain size, grain orientation, and texture. Compared to that we show how heat-treatments impact fracture resistance as well as their anisotropy in two orthogonal orientations in an LPBF-processed 18Ni-300 maraging steel.

1. Introduction

AM techniques such as LPBF often exhibit microstructural features that are distinct from counterparts that are fabricated using conventional processing routes. The rapid cooling rates, for example, can result in refined microstructures which together with melt pool-induced meso-structures have the potential to impact mechanical performance and result in orientation-dependent failure characteristics. Based on the printed alloy system, however, damage-tolerance may not have fully developed after printing and subsequent heat-treatments be required to obtain peak performance in material properties such as fracture toughness. To understand the impact of process parameters on *R*-curve behavior we have used AlSi10Mg which is known to exhibit melt pool boundaries that are strongly impacted by printing parameters. Compared to that, we have characterized 18Ni-300 maraging steel that has strong melt pool boundary characteristics to understand how AM-processing impacts materials that are less impacted by printing parameters.

2. Results

The *R*-curve behavior of LPBF-processed AlSi10Mg has been investigated to understand the effect of build parameters such as layer thickness, hatch spacing and scan strategy on the structure and mechanical properties. Fracture toughness in different orientations was tested and failure characteristics were analyzed and correlated with microstructure morphology and anisotropy. Results show that the processing parameters used for LPBF strongly influence the microstructure and melt pool morphology of the material. Increasing hatch spacing and layer thickness result in larger columnar grains with a wider cellular sub-structure whereas scan strategy controls the melt pool arrangement and the formation of a melt pool dominated mesostructure. Scan strategy, however, has significantly more impact on fracture toughness than the other two factors and a size-independent fracture toughness, K_{JIc}, ranging between ~20–30 MPa√m has been determined for LPBF AlSi10Mg. Additionally, crack plane orientation and crack propagation direction with respect to the build direction and melt pool morphology strongly affect fracture toughness values and *R*-curve behavior (Fig. 1a). Both crack initiation toughness and crack propagation resistance are higher when the melt pool mesostructure promotes more crack deflection and a more tortuous crack path. Material built with a 90° scan strategy has reduced fracture toughness (ranging from ~19–27 MPa√m) compared to material built with a 67° scan strategy (which is in the range of ~25–31 MPa√m). This difference is associated with a less tortuous crack propagation path in the material with the 90° scan strategy resulting from the formation of two distinct melt pool orientations as compared to a random melt pool arrangement in the 67° material.

Compared to that, for LPBF-processed 18Ni-300 maraging steel – the material that has strong melt pool boundary characteristics – the impact of three heat treatments (direct aging, solution treatment + aging, and thermal cycling + aging) on the structure and mechanical properties was investigated. Specifically, the *R*-curve behavior was studied in two different orthogonal orientations and failure characteristics analyzed and correlated with microstructure and phase evolution during the heat-treatments. Results show that a solution treatment of LPBF-processed maraging steel dissolves LPBF-characteristic cellular sub-structures and melt pool mesostructures. As a result, the ductility and fracture toughness are significantly reduced such that the *R*-curve behavior is comparable to cast + aged material. Direct aging causes geometrically necessary dislocations in the typical LPBF cellular substructure to hinder dislocation motion within the cellular walls while simultaneously acting as soft barrier that enables continuous plastic flow. This results in enhanced crack resistance and improved fracture properties compared to the cast + aged material. Thermal cycling prior to aging enables the formation of 10–12 vol.% reverted austenite within the martensitic matrix that in turn enables a transformation-induced plasticity (TRIP) mechanism that results in a >50% increase in fracture toughness (Fig. 1b). Strong intra- and inter-layer bonding combined with a lack of texture results in near-isotropic failure characteristics of *R*-curve behavior.

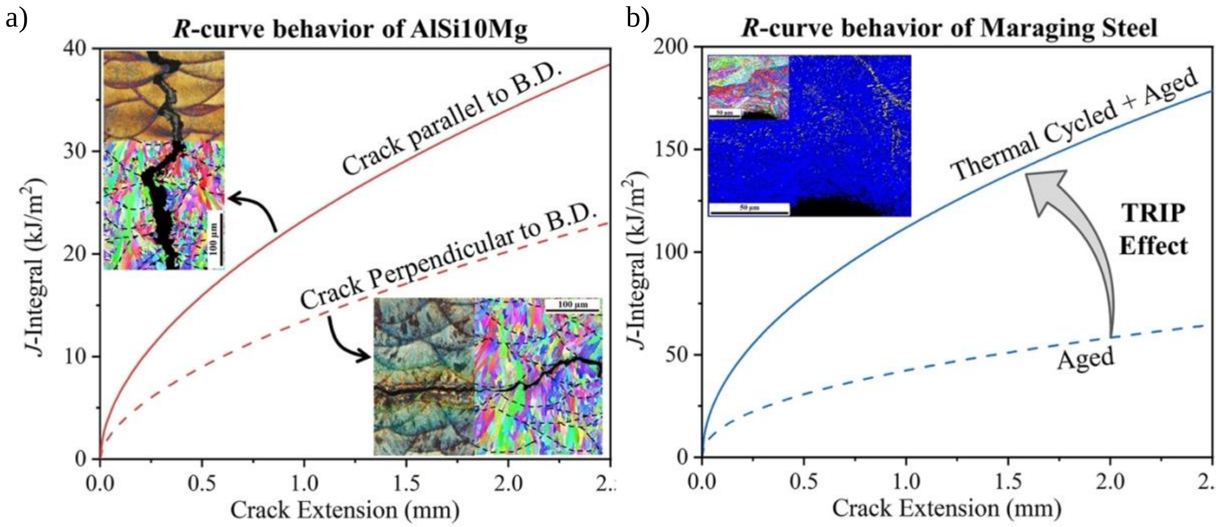

Fig.1 – Impact of (a) testing orientation on the crack resistance curve behavior of AlSi10Mg, and (b) heat-treatment on the fracture resistance of 18Ni-300 maraging steel.

3. Conclusions

Our work on AlSi10Mg reveals that micro- and meso-structural features that depend on the various processing parameters significantly affect the fracture toughness of the material. In the 18Ni-300 maraging steel, on the other hand, solution heat-treatment dissolves LPBF-characteristic cellular sub-structures and melt pool meso-structures thereby disabling AM-features that are required for mechanical performance. However, the combination of thermal cycling + aging without prior solution treatment enables a location-specific transformation-induced plasticity (TRIP) mechanism that results in significantly enhanced fracture toughness thereby providing damage-tolerance at a level that cannot be achieved in cast material.

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