	Experiment title: Evaluation of inter-phase strains present in as-built and heat treated LPBF AlSi10Mg materials	**Experiment number**: MA-5011
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Report:

Abstract

Laser Powder Bed Fused (LPBF) AlSi10Mg materials exhibit increased as-built yield strength when compared to conventional as-built cast products due to the fine silicon network and fine grain size resulting from the very fast cooling rates occurring after the laser-induced melting. However, these fast cooling rates lead to the generation of both long-range residual stresses (RS) and short range intergranular and interphase stresses, the latter between the Al-alpha matrix and the Si eutectic phase. The experiment aimed at investigationg the role of the Al/Si interphase stresses and strains.

Experimental set-up

Single Etch Notch Bending (SENB) (110 x 19 x 6 mm prisms with a 5 mm long notch machined at the mid height) specimens for fatigue crack propagation testing where measured in three different heat treated (HT) conditions: as-built (AB), after 1 hour at 165°C (HT1) and after 2 hours at 300°C (HT2).

The analyser crystal set-up on ID22A allowed the mapping of the strains from the bulk to the surface and around the notch without pseudo strains corrections from partial immersion of the gauge volume (only geometric position corrections required). The high beam energy of 60 KeV permited the BD strain to be measured in 2 orientations (also through the 19 mm thickness) to probe all the expected strain gradients. The geometry and the measured points are shown in Figure 1.

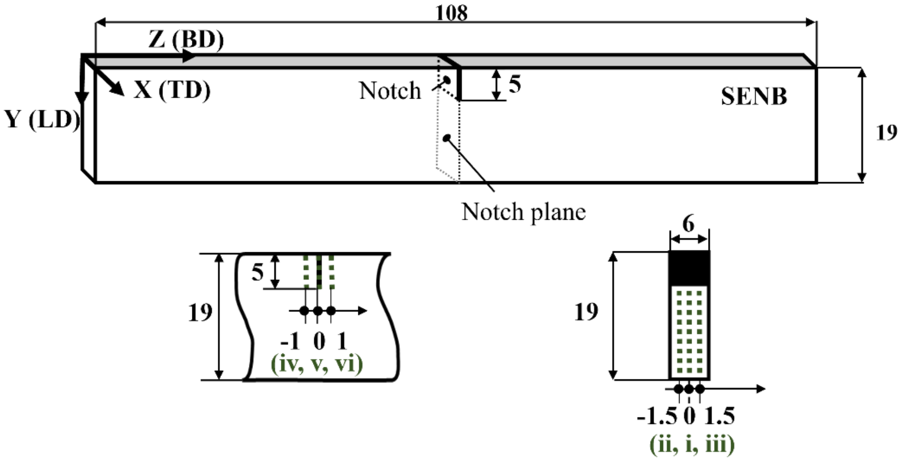

Figure 1: Geometry and measured lines: three lines in the notch plane in the centre (i) and at -1.5 mm (ii) and +1.5 mm(iii). (v) one line within the notch in the centre of the notch plane and two lines (iv) under and (vi) above the notch.

The experiment was performed with a monochromatic beam at 60 keV in transmission mode, with a beam size of 2 mm x 0.225 mm, and with a 9-channel multianalyser detector. Three lines in the notch plane (lines (i), (ii), (iii) - 15 points each) were measured in the BD and LD directions, with the sample mounted vertically and horizontally. 4 points on three lines (iv) above, (v) within and (vi) under the notch in the middle of the notch plane were measured in the BD and LD directions. The notch was probed using partially immersed gauge volumes.
θ/2θ scanning was performed to maintain the scattering vector in the same strain direction. The counting time was around 5.5 min for point in order to scan the angular range covering the Al {311} peak (2θ~9.5°) and the Si {220} and {311} peaks (2θ~6.1 ° and 7.2°, respectively).
d_0 was measured on EDM extracted cubes (three cubes per HT condition) from twin specimens (macro-stresses relaxed, baseline for the Al phase) and extracted deposits of the Si network via preferential chemical etching of the Al phase. The deposits was mounted in 1 mm-glass capillaries.

Results

The Al/Si interphase stresses were calculatedin the hypothesis of plane stress (RS negligible in the TD). In Figure 2, the results for the BD component in the notch plane centre (line (i) in Figure 1) are shown. Similar behaviour is observe for lines (ii) and (iii). The evolution of the Al {311} (in blue), and the Si {220} (in orange) and {331} (in grey) stresses after heat treatment is shown.

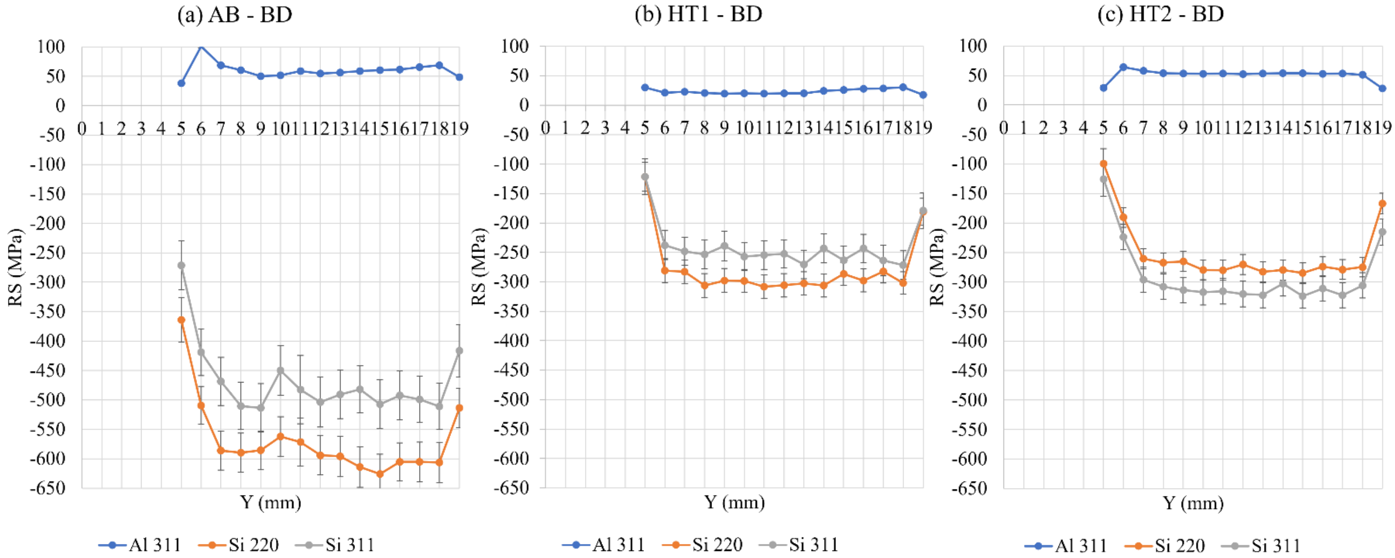

Figure 2: RS in the BD direction of the Al 311, Si 220 and Si 311.

The aluminium matrix, moving away from the zone affected by the notch (Y>8~mm), exhibits a flat tensile stress profile with an average value of ~60 MPa in the AB condition, ~23 MPa after HT1 and ~53 MPa after HT2. Oppositely, the silicon phase undergoes compressive RS: -495 MPa in the AB condition, -255 MPa after HT1 and -315 MPa after HT2. The Si {311} diffraction peak is assumed as representative of macrostresses, as the least affected by intergranular strains.
The AB microstructure consists of sub-micron Al grains, decorated by a nanometric silicon phase (with a diamond crystal structure) and enclosed by an almost continuous eutectic silicon network. Part of the Si and Mg atoms is in a supersaturated solid solution in the aluminium matrix. HT1 induces the Si precipitation from the Al matrix, while the eutectic network structure is still retained. HT1 induces a RS relief in both the matrix and the eutecic silicon phase Figure 2a-b.
After HT2, the metastable as-built microstructure evolves towards a more stable condition with the formation of globulized Si particles through the disintegration of the Al/Si eutectic network. This seems to lead to an increase in RS (Figure 2c).
The measurements on the lines (iv), (v), (vi) around the notch showed comparable results: the gradient in the BD is negligible. Therefore the use of a 2 mm x 0.225 mm beam is appropriate to measure the BD and LD components.
The measurements within the notch, line (v), were used to calculate a d_0 stress-free reference, since a plane-stress boundary condition can be assumed at the notch faces. The results were compared with the measurements from the coupons.
The results show a good agreement (see Table 1).

Table 1: Stress-free reference d_0 results.

	Si {220}	*Si {311}*	*Al {311}*	
	Powder	Powder	Coupons	Notch
AB	1.9242 ±0.0001	1.6417 ±0.0001	1.22189 ±0.00001	1.22221 ±0.00001
HT1	1.92084 ±0.00007	1.63894 ±0.00008	1.22182 ±0.00002	1.22227 ±0.00002
HT2	1.92073 ±0.00006	1.6383 ±0.0001	1.22192 ±0.00003	1.22209 ±0.00003

Conclusion

Different techniques to ensure a reliable value of d_0 were applied (notch measurements and extracted coupons) giving comparable results.

The distribution of the RS between the aluminium matrix and the eutectic silicon was investigated by the measurements of the Al {331} and Si {311} diffraction peaks. The evolution of the stresses after heat treatment was quantified.