Experimental report

01/03/2022

Proposal: 1-02-341 **Council:** 4/2021

Title: Residual stress state and Evolution during fatigue crack propagation Additively Manufactured 316L austenitic stainless steels

Research area: Materials

This proposal is a resubmission of 1-02-304

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Local contacts: Thilo PIRLING

Samples: 316L austenitic stainless steel Fe18Cr12Ni2Mo0.8Mn9.4Si0.2C0.08N

Instrument	Requested days	Allocated days	From	To
SALSA	2	2	30/08/2021	01/09/2021

Abstract:

Additive manufacturing (AM) has evolved from a technology for rapid prototyping and starts to become a matured production process used in several industries. Laser Powder Bed Fusion (LPBF) is a AM technology which allows to fabrication of complex structures, which cannot be produced conventionally via subtractive manufacturing methods. The high temperature gradients during the LPBF process introduces residual stresses into the produced structures, which can impact both the production (cracking, distortion) and subsequent mechanical properties (mean stress in fatigue). This proposed experiment aims to explore the residual stress in fatigue crack growth specimens and the Evolution of residual stresses following fatigue loading in the presence of an advancing fatigue crack. In particular characterise the stability of the residual stresses under an advanced fatigue crack and observe the redistribution of the residual stress profile found in LPBF specimens.

Residual stress state and evolution during fatigue crack propagation Additively Manufactured 316L austenitic stainless steels

Preliminary experimental report (proposal 1-02-341)

Experiment requested 2 days, awarded 2 days
Experiment scheduled 30/08/2021 - 01/09/2021

Aims

This proposed experiment aimed to explore the residual stress evolution following fatigue crack growth in LPBF 316L.

- The first aim was to characterise the evolution of the residual stresses under an advanced fatigue crack corresponding to the maximum crack growth rate (2mm growth) and observe the redistribution of the RS profile found in LPBF specimens. This is crucial for the lifing activities of LPBF structures.
- The second aim was to characterise the RS state in “miniature” SENB specimens which have been extracted from a LPBF wall at 0°, 45° and 90° to the build plate to understand the growth rates as a function of angle of the crack compared to the directional microstructure.

Experiment

The experiment studied 4x SENB (Single Edge Notch Bending) specimens manufactured from LPBF 316L

- SENB A same geometry as measured in 1-02-257 but with a crack which has propagated 2mm, see Figure 2. The measurements are at the centre thickness at 3 heights relative to the crack.
- SENB B and SENB D specimens are “mini” versions of the SENB geometry with a dimension 3x6x64mm, which have been extracted from a 80x80x13mm LPBF vertical wall in 3 orientations, 0°, 45° and 90° to the baseplate.

Following discussion with the local contact, the monochromator was set to give a diffraction angle $2\theta=105°$ for the (311)-reflection of austenitic Fe. The optics used for the experiment were adjusted through the experiment to give the highest spatial resolution for the three components of strain investigated. The experiment started with the 0.6 mm horizontal and 2 mm vertical primary collimator and the 0.6 mm secondary collimator. The optics were changed to 0.6mm vertical and 2mm horizontal primary and secondary to optimize the measurement of the normal building direction in the SENB geometry. In total set-up time included monochromator scans, collimator optic alignments
The specimens successfully measured are summarised as the following;

- Machined SENB with 2mm crack grown from the EDM's pre-notch (3 lines around the crack plane and far field)
- 3x mini SENB specimens (horizontal, vertical, diagonal) (line at crack plan, far field and vertical scan)
- D0 cubes

Due to the faster than expected counting time resulting from the reparation of the detector since our previous measurement with this geometry (1-02-257), test measurements were performed on 2 extra geometries.

- Machined SENB, non-cracked in hot rolled 316L (baseline for crack propagation testing) (crack plane and far field)
- Machined SENB specimen heat treated at designed to relax the RS (further condition for crack propagation testing at BAM) (crack plane and far field)

Initial results

All the diffraction peaks have been fitting and an initial analysis of the residual strains have been completed. The residual stresses in the specimen with the grown crack was the focus of the preliminary focus study and have been calculated. The results already shown the evolution of residual stress under the advancing fatigue crack. The residual strain distribution of the build direction component in cracked SENB is shown in Figure 1. The final data will be reported in the final experimental report

(a)

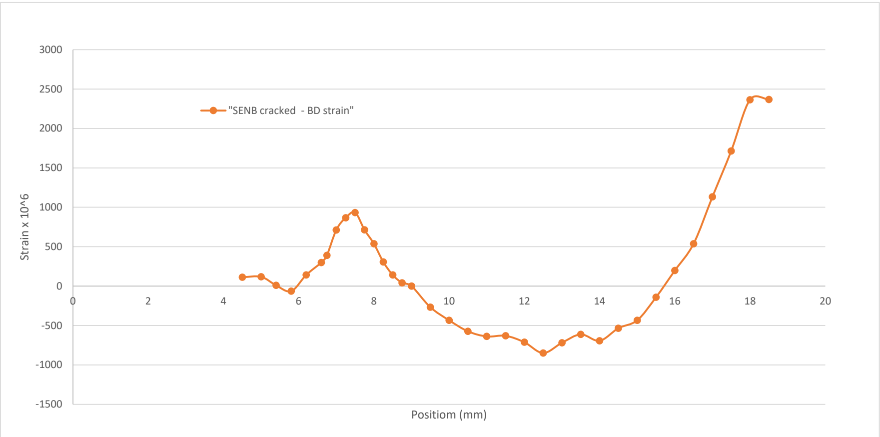

Figure 1. Residual strains in the build direction for the SENB with 2mm of crack growth

Outcomes

In summary, the experiment is considered successful in terms of measuring the effect of crack advanced on the residual stress field in AM 316L. The data is also planned to support the validation of finite element models of the residual stress state in the crack propagation specimen geometry and an associated publication.