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| ESRF | **Experiment title:**<br>*In situ* computed laminography studies of aerospace materials failure | **Experiment number**:<br>MA1006 |
| **Beamline**:<br>ID19 | **Date of experiment**:<br>from: 24-04-10 to: 26-04-10 | **Date of report**:<br>30-3-15 |
| **Shifts:**<br>6 | **Local contact(s)**:<br>Lukas Helfen | *Received at ESRF:* |


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## Report:

The combined use of carbon fibre composites and high strength aluminium alloys can be expected to be a theme of aircraft construction for years to come. Innovative data from this experiment has provided unique levels of materials science detail and real engineering relevance to damage tolerance and durability understanding in these two key classes of lightweight transport material. The results have been used for the following ISI listed journal publications:

***Ductile crack initiation and propagation assessed via in situ synchrotron radiation-computed laminography***
By:Morgeneyer, TF (Morgeneyer, T. F.); Helfen, L (Helfen, L.); Sinclair, I (Sinclair, I.); Proudhon, H (Proudhon, H.); Xu, F (Xu, F.); Baumbach, T (Baumbach, T.).
SCRIPTA MATERIALIA, Volume: 65, Issue: 11, Pages: 1010-1013, DOI: 10.1016/j.scriptamat.2011.09.005, Published: DEC 2011
***Abstract*** Ductile crack initiation and propagation within a naturally aged aluminium alloy sheet has been observed in situ via synchrotron radiation-computed laminography, a technique specifically adapted to three-dimensional imaging of thin objects that are laterally extended. Voids and intermetallic particles, and their subsequent evolution during ductile crack extension at different associated levels of stress triaxiality, were clearly observed within fracture coupons of a reasonable engineering length-scale, overcoming the conventional sample size limitation of computed tomography at high resolutions.
CURRENT ISI CITATIONS = 21 (March 2015)

***Synchrotron and neutron laminography for three-dimensional imaging of devices and flat material specimens***
By:Helfen, L (Helfen, Lukas); Morgeneyer, TF (Morgeneyer, Thilo F.); Xu, F (Xu, Feng); Mavrogordato, MN (Mavrogordato, Mark N.); Sinclair, I (Sinclair, Ian); Schillinger, B (Schillinger, Burkhard); Baumbach, T (Baumbach, Tilo)
INTERNATIONAL JOURNAL OF MATERIALS RESEARCH, Volume: 103, Issue: 2, Pages: 170-173, DOI:10.3139/146.110668, Published: FEB 2012
***Abstract*** Computed laminography has been introduced to synchrotron and neutron imaging set-ups to complement computed tomography for three-dimensional imaging of laterally extended (i. e. plate-like) specimens. The wide application field of computed laminography due to different contrast modes (X-ray or neutron absorption and X-ray

phase contrast) and spatial resolutions ranging from some 100 down to approximately 0.5 mu m is demonstrated. Selected examples from device inspection and from materials science are reported. They outline the interest of the method for non-destructive and in-situ measurements of regions of interest in large planar specimens where engineering-relevant boundary conditions have to be met. With a materials science background, the in-situ investigation of crack propagation in aluminium sheets and carbon-fibre composite panels under mechanical loading is reported.
CURRENT ISI CITATIONS = 8 (March 2015)

***A comparison of multi-scale 3D X-ray tomographic inspection techniques for assessing carbon fibre composite impact damage***
By:Bull, DJ (Bull, D. J.); Helfen, L (Helfen, L.); Sinclair, I (Sinclair, I.); Spearing, SM (Spearing, S. M.); Baumbach, T (Baumbach, T.)
COMPOSITES SCIENCE AND TECHNOLOGY, Volume: 75, Pages: 55-61, DOI: 10.1016/j.compscitech.2012.12.006, Published: FEB 11 2013
***Abstract*** Tomographic imaging using both laboratory sources and synchrotron radiation (SR) was performed to achieve a multi-scale damage assessment of carbon fibre composites subjected to impact damage, allowing various internal damage modes to be studied in three-dimensions. The focus of this study is the comparison of different tomographic methods, identifying their capabilities and limitations, and their use in a complementary manner for creating an overall 3D damage assessment at both macroscopic and microscopic levels. Overall, microfocus laboratory computed tomography (mu CT) offers efficient routine assessment of damage at mesoscopic and macroscopic levels in engineering-scale test coupons and relatively high spatial resolutions on trimmed-down samples; whilst synchrotron radiation computed tomography (SRCT) and computed laminography (SRCL) offer scans with the highest image quality, particularly given the short acquisition times, allowing damage micromechanisms to be studied in detail.
CURRENT ISI CITATIONS = 12 (March 2015)

***Three-dimensional assessment of low velocity impact damage in particle toughened composite laminates using micro-focus X-ray computed tomography and synchrotron radiation laminography***
By:Bull, DJ (Bull, D. J.); Spearing, SM (Spearing, S. M.); Sinclair, I (Sinclair, I.); Helfen, L (Helfen, L.)
COMPOSITES PART A-APPLIED SCIENCE AND MANUFACTURING , Volume: 52, Pages: 62-69, DOI:10.1016/j.compositesa.2013.05.003, Published: SEP 2013
***Abstrac*** Results are presented studying the contribution of particle toughening to impact damage resistance in carbon fibre reinforced polymer materials. Micro-focus X-ray computed tomography and synchrotron radiation computed laminography were used to provide a novel, multiscale approach for assessing impact damage. Thin (1 mm thick) composite plates containing either untoughened or particle-toughened resin systems were subjected to low velocity impact. Damage was assessed three-dimensionally at voxel resolutions of 0.7 mu m and 4.3 mu m using SRCL and mu CT respectively; the former being an innovative approach to the laterally extended geometry of CFRP plates. Observations and measurements taken from mu CT scans captured the full extent of impact damage on both material systems revealing an interconnected network of intra- and inter-laminar cracks. These lower resolution images reveal that the particle-toughened system suppresses delaminations with little effect on intralaminar damage. The higher resolution images reveal that the particles contribute to toughening by crack deflection and bridging.
CURRENT ISI CITATIONS = 3 (March 2015)

***In situ 3-D observation of early strain localization during failure of thin Al alloy (2198) sheet***
By:Morgeneyer, TF (Morgeneyer, Thilo F.); Taillandier-Thomas, T (Taillandier-Thomas, Thibault); Helfen, L (Helfen, Lukas); Baumbach, T (Baumbach, Tilo); Sinclair, I (Sinclair, Ian); Roux, S (Roux, Stephane); Hild, F (Hild, Francois)
ACTA MATERIALIA, Volume: 69, Pages: 78-91, DOI: 10.1016/j.actamat.2014.01.033, Published: MAY 2014
***Abstract*** High-resolution in situ synchrotron X-ray laminography combined with digital volume correlation (DVC) is used to measure the damage and plastic strain fields ahead of a notch introduced within a 2198 Al-Cu-Li alloy sheet. Synchrotron laminography is a technique specifically developed for three-dimensional (3-D) imaging of laterally extended sheet specimens with micrometre resolution. DVC is carried out using the 3-D image contrast caused by iron-rich intermetallic particles present in the alloy. The alloy is recrystallized and tested in T8 artificial ageing condition involving relatively low work hardening. Inclined strain localization bands are shown to develop at similar to 800 mu m from the notch prior to the onset of damage. Damage in this region results mainly from the nucleation of voids on micrometric intermetallic particles and occurs at a very late stage of deformation, followed by very limited void growth. The accumulation of strain in the slanted localization band is found to be a steady process, whereas the crack propagation is a sudden process. Standard 3-D FE calculations using either von Mises plasticity or Gurson's model do not capture the plastic localization process. (C) 2014 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.
CURRENT ISI CITATIONS = 5 (March 2015)